060,872

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 251 446 A2

EUROPEAN PATENT APPLICATION

(12)

(51) Int.Cl.³: C 12 N 15/00
C 12 N 9/54, C 12 N 1/00

(21) Application number: 87303761.8

(22) Date of filing: 28.04.87

(30) Priority: 30.04.86 US 858594
06.04.87 US 35652

(43) Date of publication of application:
07.01.88 Bulletin 88/1

(84) Designated Contracting States:
AT BE CH DE ES FR GB GR IT LI LU NL SE

(71) Applicant: GENENTECH, INC.
460 Point San Bruno Boulevard
South San Francisco California 94080(US)

(72) Inventor: Wells, James Allen
64 Otay Avenue
San Mateo CA 94403(US)

(72) Inventor: Cunningham, Brian C.
24 Olive Avenue
Piedmont CA 94611(US)

(72) Inventor: Caldwell, Robert Mark
1828 Broadway
No.101 San Francisco Ca 94109(US)

(72) Inventor: Bott, Richard Ray
3032 Hillside drive
Burlingame CA 94010(US)

(72) Inventor: Estell, David Aaron
250 Diablo Avenue
Mountan View CA 94043(US)

(72) Inventor: Power, Scott Douglas
732 Olive Court
San Bruno CA 94066(US)

(74) Representative: Bizley, Richard Edward et al,
BOULT, WADE & TENNANT 27 Furnival Street
London EC4A 1PQ(GB)

(54) **Non-human Carbonyl hydrolase mutants, DNA sequences and vectors encoding same and hosts transformed with said vectors.**

(57) Novel carbonyl hydrolase mutants derived from the amino acid sequence of naturally-occurring or recombinant non-human carbonyl hydrolases and DNA sequences encoding the same. The mutant carbonyl hydrolases, in general, are obtained by *in vitro* modification of a precursor DNA sequence encoding the naturally-occurring or recombinant carbonyl hydrolase to encode the substitution, insertion or deletion of one or more amino acids in the amino acid sequence of a precursor carbonyl hydrolase. Such mutants have one or more properties which are different than the same property of the precursor hydrolase.

EP 0 251 446 A2

Croydon Printing Company Ltd.

NON-HUMAN CARBONYL HYDROLASE MUTANTS, DNA SEQUENCES AND VECTORS ENCODING SAME AND HOSTS TRANSFORMED WITH SAID VECTORS

The recent development of various *in vitro* techniques to manipulate the DNA sequences encoding naturally-occuring polypeptides as well as recent developments in the chemical synthesis of relatively short sequences of single and double stranded DNA has resulted in the speculation that such techniques can be used to modify enzymes to improve some functional property in a predictable way. Ulmer, K.M. (1983) *Science* 219, 666-671. The only working example disclosed therein is the substitution of a single amino acid within the active site of tyrosyl-tRNA synthetase (Cys35→Ser) which lead to a reduction in enzymatic activity. See Winter, G., et al. (1982) *Nature* 299, 756-758; and Wilkinson, A.J., et al. (1983) *Biochemistry* 22, 3581-3586 (Cys35→Gly mutation also resulted in decreased activity).

When the same t-RNA synthetase was modified by substituting a different amino acid residue within the active site with two different amino acids, one of the mutants (Thr51→Ala) reportedly demonstrated a predicted moderate increase in kcat/Km whereas a second mutant (Thr51→Pro) demonstrated a massive increase in kcat/Km which could not be explained with

certainty. Wilkinson, A.H., et al. (1984) Nature 307, 187-188.

Another reported example of a single substitution of an amino acid residue is the substitution of cysteine for isoleucine at the third residue of T4 lysozyme. Perry, L.J., et al. (1984) Science 226, 555-557. The resultant mutant lysozyme was mildly oxidized to form a disulfide bond between the new cysteine residue at position 3 and the native cysteine at position 97. This crosslinked mutant was initially described by the author as being enzymatically identical to, but more thermally stable than, the wild type enzyme. However, in a "Note Added in Proof", the author indicated that the enhanced stability observed was probably due to a chemical modification of cysteine at residue 54 since the mutant lysozyme with a free thiol at Cys54 has a thermal stability identical to the wild type lysozyme.

Similarly, a modified dihydrofolate reductase from E.coli has been reported to be modified by similar methods to introduce a cysteine which could be crosslinked with a naturally-occurring cysteine in the reductase. Villafranca, D.E., et al. (1983) Science 222, 782-788. The author indicates that this mutant is fully reactive in the reduced state but has significantly diminished activity in the oxidized state. In addition, two other substitutions of specific amino acid residues are reported which resulted in mutants which had diminished or no activity.

EPO Publication No. 0130756 discloses the substitution of specific residues within B. amyloliquefaciens subtilisin with specific amino acids. Thus, Met222 has been substituted with all 19 other amino acids,

Gly166 with 9 different amino acids and Gly169 with Ala and Ser.

As set forth below, several laboratories have also reported the use of site directed mutagensis to produce the mutation of more than one amino acid residue within a polypeptide.

The amino-terminal region of the signal peptide of the prolipoprotein of the E. coli outer membrane was stated to be altered by the substitution or deletion of residues 2 and 3 to produce a charge change in that region of the polypeptide. Inoyye, S., et al. (1982) Proc. Nat. Acad. Sci. USA 79, 3438-3441. The same laboratory also reported the substitution and deletion of amino acid redisues 9 and 14 to determine the effects of such substitution on the hydrophobic region of the same signal sequence. Inouye, S., et al. (1984) J. Biol. Chem. 259, 3729-3733.

Double mutants in the active site of tyrosyl-t-RNA synthetase have also been reported. Carter, P.J., et al. (1984) Cell 38, 835-840. In this report, the improved affinity of the previously described Thr51→Pro mutant for ATP was probed by producing a second mutation in the active site of the enzyme. One of the double mutants, Gly35/Pro51, reportedly demonstrated an unexpected result in that it bound ATP in the transition state better than was expected from the two single mutants. Moreover, the author warns, at least for one double mutant, that it is not readily predictable how one substitution alters the effect caused by the other substitution and that care must be taken in interpreting such substitutions.

A mutant is disclosed in U.S. Patent No. 4,532,207, wherein a polyarginine tail was attached to the C-terminal residue of β-urogastrone by modifying the DNA sequence encoding the polypeptide. As disclosed, the polyarginine tail changed the electrophoretic mobility of the urogastrone-polyaginine hybrid permiting selective purification. The polyarginine was subsequently removed, according to the patentee, by a polyarginine specific exopeptidase to produce the purified urogastrone. Properly construed, this reference discloses hybrid polypeptides which do not constitute mutant polypeptides containing the substitution, insertion or deletion of one or more amino acids of a naturally occurring polypeptide.

Single and double mutants of rat pancreatic trypsin have also been reported. Craik, C.S., et al. (1985) Science 228, 291-297. As reported, glycine residues at positions 216 and 226 were replaced with alanine residues to produce three trypsin mutants (two single mutants and one double mutant). In the case of the single mutants, the authors stated expectation was to observe a differential effect on Km. They instead reported a change in specificity (kcat/Km) which was primarily the result of a decrease in kcat. In contrast, the double mutant reportedly demonstrated a differential increase in Km for lysyl and arginyl substrates as compared to wild type trypsin but had virtually no catalytic activity.

The references discussed above are provided solely for their disclosure prior to the filing date of the instant case, and nothing herein is to be construed as an admission that the inventors are not entitled to antedate such disclosure by virtue of prior invention or priority based on earlier filed applications.

Based on the above references, however, it is apparent that the modification of the amino acid sequence of wild type enzymes often results in the decrease or destruction of biological activity.

Accordingly, it is an object herein to provide carbonyl hydrolase mutants which have at least one property which is different from the same property of the carbonyl hydrolase precursor from which the amino acid of said mutant is derived.

It is a further object to provide mutant DNA sequences encoding such carbonyl hydrolase mutants as well as expression vectors containing such mutant DNA sequences.

Still further, another object of the present invention is to provide host cells transformed with such vectors as well as host cells which are capable of expressing such mutants either intracellularly or extracellularly.

Summary of the Invention

The invention includes carbonyl hydrolase mutants, preferably having at least one property which is substantially different from the same property of the precursor non-human carbonyl hydrolase from which the amino acid sequence of the mutant is derived. These properties include oxidative stability, substrate, specificity catalytic activity, thermal stability, alkaline stability, pH activity profile and resistance to proteolytic degradation. The precursor carbonyl hydrolase may be naturally occurring carbonyl hydrolases or recombinant carbonyl hydrolases. The amino acid sequence of the carbonyl hydrolase mutant is derived by the substitution, deletion or insertion of one or more amino acids of the precursor carbonyl hydrolase amino acid sequence.

The invention also includes mutant DNA sequences encoding such carbonyl hydrolase mutants. Further the invention includes expression vectors containing such mutant DNA sequences as well as host cells transformed with such vectors which are capable of expressing said carbonyl hydrolase mutants.

Brief Description of the Drawings

Figure 1 shows the nucleotide sequence of the coding strand, correlated with the amino acid sequence of B. amyloliquefaciens subtilisin gene. Promoter (p) ribosome binding site (rbs) and termination (term) regions of the DNA sequence as well as sequences encoding the presequence (PRE) putative prosequence (PRO) and mature form (MAT) of the hydrolase are also shown.

Figure 2 is a schematic diagram showing the substrate binding cleft of subtilisin together with substrate.

Figure 3 is a stereo view of the S-1 binding subsite of B. amyloliquefaciens subtilisin showing a lysine P-1 substrate bound in the site in two different ways. Figure 3A shows Lysine P-1 substrate bound to form a salt bridge with a Glu at position 156. Figure 3B shows Lysine P-1 substrate bound to form a salt bridge with Glu at position 166.

Figure 4 is a schematic diagram of the active site of subtilisin Asp32, His64 and Ser221.

Figures 5A and 5B depict the amino acid sequence of subtilisin obtained from various sources. The residues directly beneath each residue of B. amyloliquefaciens subtilisin are equivalent residues which (1) can be mutated in a similar manner to that described for B. amyloliquefaciens subtilisin, or (2) can be used as a replacement amino acid residue in B. amyloliquefaciens subtilisin. Figure 5C depicts conserved residues of B. amyloliquefaciens subtilisin when compared to other subtilisin sequences.

Figures 6A and 6B depict the inactivation of the mutants Met222L and Met222Q when exposed to various organic oxidants.

Figure 7 depicts the ultraviolet spectrum of Met222F subtilisin and the difference spectrum generated after inactivation by diperdodecanoic acid (DPDA).

Figure 8 shows the pattern of cyanogen bromide digests of untreated and DPDA oxidized subtilisin Met222F on high resolution SDS-pyridine peptide gels.

Figure 9 depicts a map of the cyanogen bromide fragments of Fig. 8 and their alignment with the sequence of subtilisin Met222F.

Figure 10 depicts the construction of mutations between codons 45 and 50 of B. amyloliquefaciens subtilisin.

Figure 11 depicts the construction of mutations between codons 122 and 127 of B. amyloliquefaciens subtilisin.

Figure 12 depicts the effect of DPDA on the activity of subtilisin mutants at positions 50 and 124 in subtilisin Met222F.

Figure 13 depicts the construction of mutations at codon 166 of B. amyloliquefaciens subtilisin.

Figure 14 depicts the effect of hydrophobicity of the P-1 substrate side-chain on the kinetic parameters of wild-type B. amyloliquefaciens subtilisin.

Figure 15 depicts the effect of position 166 side-chain substitutions on P-1 substrate specificity. Figure 15A shows position 166 mutant subtilisins containing non-branched alkyl and aromatic side-chain substitutions arranged in order of increasing molecular volume. Figure 15B shows a series of mutant enzymes progressing through β- and γ-branched aliphatic side chain substitutions of increasing molecular volume.

Figure 16 depicts the effect of position 166 side-chain volumn on log kcat/Km for various P-1 substrates.

Figure 17 shows the substrate specificity differences between Ile166 and wild-type (Gly166) B. amyloliquefaciens subtilisin against a series of alphatic and aromatic substrates. Each bar represents the difference in log kcat/Km for Ile166 minus wild-type (Gly166) subtilisin.

Figure 18 depicts the construction of mutations at codon 169 of B. amyloliquefaciens subtilisin.

Figure 19 depicts the construction of mutations at codon 104 of B. amyloliquefaciens subtilisin.

Figure 20 depicts the construction of mutations at codon 152 B. amyloliquefaciens subtilisin.

Figure 21 depicts the construction of single mutations at codon 156 and double mutations at codons 156 and 166 of B. amyloliquefaciens subtilisin.

Figure 22 depicts the construction of mutations at codon 217 for B. amyloliquefaciens subtilisin.

Figure 23 depicts the kcat/Km versus pH profile for mutations at codon 156 and 166 in B. amyloliquefaciens subtilisin.

Figure 23A depicts the kcat/Km versus pH profile for mutations at codon 156 and 166 in B. amyloliquefaciens subtilisin.

Figure 24 depicts the kcat/Km versus pH profile for mutations at codon 222 in B. amyloliquefaciens subtilisin.

Figure 25 depicts the constructing mutants at codons 94, 95 and 96.

Figures 26 and 27 depict substrate specificity of various wild type and mutant subtilisins for different substrates.

Figures 28 A, B, C and D depict the effect of charge in the P-1 binding sites due to substitutions at codon 156 and 166.

Figures 29 A and B are a stereoview of the P-1 binding site of subtilisin BPN' showing a lysine P-1 substrate bound in the site in two ways. In 29A, Lysine P-1 substrate is built to form a salt bridge with a Glu at codon 156. In 29B, Lysine P-1 substrate is built to form a salt bridge with Glu at codon 166.

Figure 30 demonstrates residual enzyme activity versus temperature curves for purified wild-type (Panel A), C22/C87 (Panel B) and C24/C87 (Panel C).

Figure 31 depicts the strategy for producing point mutations in the subtilisin coding sequence by misincorporation of $^{\alpha}$-thioldeoxynucleotide triphosphates.

Figure 32 depicts the autolytic stability of purified wild type and mutant subtilisins 170E, 107V, 213R and 107V/213R at alkaline pH.

Figure 33 depicts the autolytic stability of purified wild type and mutant subtilisins V50, F50 and F50/V107/R213 at alkaline pH.

Figure 34 depicts the strategy for constructing plasmids containing random cassette mutagenesis over residues 197 through 228.

Figure 35 depicts the oligodeoxynucleotides used for random cassette mutagenesis over residues 197 through 228.

Figure 36 depicts the construction of mutants at codon 204.

Figure 37 depicts the oligodeoxynucleotides used for synthesizing mutants at codon 204.

Detailed Description

The inventors have discovered that various single and multiple *in vitro* mutations involving the substitution, deletion or insertion of one or more amino acids within a non-human carbonyl hydrolase amino acid sequence can confer advantageous properties to such mutants when compared to the non-mutated carbonyl hydrolase.

Specifically, *B. amyloliquefaciens* subtilisin, an alkaline bacterial protease, has been mutated by modifying the DNA encoding the subtilisin to encode the substitution of one or more amino acids at various amino acid residues within the mature form of the subtilisin molecule. These *in vitro* mutant subtilisins have at least one property which is different when compared to the same property of the precursor subtilisin. These modified properties fall into several categories including: oxidative stability, substrate specificity, thermal stability, alkaline stability, catalytic activity, pH activity

profile, resistance to proteolytic degradation, Km, kcat and Km/kcat ratio.

Carbonyl hydrolases are enzymes which hydrolyze

compounds containing C-X bonds in which X is oxygen or nitrogen. They include naturally-occurring carbonyl hydrolases and recombinant carbonyl hydrolases. Naturally occurring carbonyl hydrolases principally include hydrolases, e.g. lipases and peptide hydrolases, e.g. subtilisins or metalloproteases. Peptide hydrolases include α-aminoacylpeptide hydrolase, peptidylamino-acid hydrolase, acylamino hydrolase, serine carboxypeptidase, metallocarboxy-peptidase, thiol proteinase, carboxylproteinase and metalloproteinase. Serine, metallo, thiol and acid proteases are included, as well as endo and exo-proteases.

"Recombinant carbonyl hydrolase" refers to a carbonyl hydrolase in which the DNA sequence encoding the naturally occurring carbonyl hydrolase is modified to produce a mutant DNA sequence which encodes the substitution, insertion or deletion of one or more amino acids in the carbonyl hydrolase amino acid sequence. Suitable modification methods are disclosed herein and in EPO Publication No. 0130756 published January 9, 1985.

Subtilisins are bacterial carbonyl hydrolases which generally act to cleave peptide bonds of proteins or peptides. As used herein, "subtilisin" means a naturally occurring subtilisin or a recombinant subtilisin. A series of naturally occurring subtilisins is known to be produced and often secreted

by various bacterial species. Amino acid sequences of the members of this series are not entirely homologous. However, the subtilisins in this series exhibit the same or similar type of proteolytic activity. This class of serine proteases shares a common amino acid sequence defining a catalytic triad which distinguishes them from the chymotrypsin related class of serine proteases. The subtilisins and chymotrypsin related serine proteases both have a catalytic triad comprising aspartate, histidine and serine. In the subtilisin related proteases the relative order of these amino acids, reading from the amino to carboxy terminus is aspartate-histidine-serine. In the chymotrypsin related proteases tne relative order, however is histidine-aspartate-serine. Thus, subtilisin herein refers to a serine protease having the catalytic triad of subtilisin related proteases.

"Recombinant subtilisin" refers to a subtilisin in which the DNA sequence encoding the subtilisin is modified to produce a mutant DNA sequence which encodes the substitution, deletion or insertion of one or more amino acids in the naturally occurring subtilisin amino acid sequence. Suitable methods to produce such modification include those disclosed herein and in EPO Publication No. 0130756. For example, the subtilisin multiple mutant herein containing the substitution of methionine at amino acid residues 50, 124 and 222 with phenylalanine, isoleucine and glutamine, respectively, can be considered to be derived from the recombinant subtilisin containing the substitution of glutamine at residue 222 (Q222) disclosed in EPO Publication No. 0130756. The multiple mutant thus is produced by the substitution of phenylalanine for methionine at

residue 50 and isoleucine for methionine at residue 124 in the Q222 recombinant subtilisin.

"Carbonyl hydrolases" and their genes may be obtained from many procaryotic and eucaryotic organisms. Suitable examples of procaryotic organisms include gram negative organisms such as E. coli or pseudomonas and gram positive bacteria such as micrococcus or bacillus. Examples of eucaryotic organisms from which carbonyl hydrolase and their genes may be obtained include yeast such as S. cerevisiae, fungi such as Aspergillus sp., and non-human mammalian sources such as, for example, Bovine sp. from which the gene encoding the carbonyl hydrolase chymosin can be obtained. As with subtilisins, a series of carbonyl hydrolases can be obtained from various related species which have amino acid sequences which are not entirely homologous between the members of that series but which nevertheless exhibit the same or similar type of biological activity. Thus, non-human carbonyl hydrolase as used herein has a functional definition which refers to carbonyl hydrolases which are associated, directly or indirectly, with procaryotic and non-human eucaryotic sources.

A "carbonyl hydrolase mutant" has an amino acid sequence which is derived from the amino acid sequence of a non-human "precursor carbonyl hydrolase". The precursor carbonyl hydrolases include naturally-occurring carbonyl hydrolases and recombinant carbonyl hydrolases. The amino acid sequence of the carbonyl hydrolase mutant is "derived" from the precursor hydrolase amino acid sequence by the substitution, deletion or insertion of one or more amino acids of the precursor amino acid sequence. Such modification is of the "precursor DNA sequence" which encodes the

amino acid sequence of the precursor carbonyl hydrolase rathern than manipulation of the precursor carbonyl hydrolase per se. Suitable methods for such manipulation of the precursor DNA sequence include methods disclosed herein and in EPO Publication No. 0130756.

Specific residues of B. amyloliquefaciens subtilisin are identified for substitution, insertion or deletion. These amino acid position numbers refer to those assigned to the B. amyloliquefaciens subtilisin sequence presented in Fig. 1. The invention, however, is not limited to the mutation of this particular subtilisin but extends to precursor carbonyl hydrolases containing amino acid residues which are "equivalent" to the particular identified residues in B. amyloliquefaciens subtilisin.

A residue (amino acid) of a precursor carbonyl hydrolase is equivalent to a residue of B. amyloliquefaciens subtilisin if it is either homologous (i.e., corresponding in position in either primary or tertiary structure) or analagous to a specific residue or portion of that residue in B. amyloliquefaciens subtilisin (i.e., having the same or similar functional capacity to combine, react, or interact chemically).

In order to establish homology to primary structure, the amino acid sequence of a precursor carbonyl hydrolase is directly comparted to the B. amyloliquefaciens subtilisin primary sequence and particularly to a set of residues known to be invariant in all subtilisins for which sequence is known (Figure 5C). After aligning the conserved residues, allowing for necessary insertions and

deletions in order to maintain alignment (i.e., avoiding the elimination of conserved residues through arbitrary deletion and insertion), the residues equivalent to particular amino acids in the primary sequence of B. amyloliquefaciens subtilisin are defined. Alignment of conserved residues preferably should conserve 100% of such residues. However, alignment of greater than 75% or as little as 50% of conserved residues is also adequate to define equivalent residues. Conservation of the catalytic triad, Asp32/His64/Ser221 should be maintained.

For example, in Figure 5A the amino acid sequence of subtilisin from B. amyloliquefaciens B. subtilisin var. I168 and B. lichenformis (carlsbergensis) are aligned to provide the maximum amount of homology between amino acid sequences. A comparison of these sequences shows that there are a number of conserved residues contained in each sequence. These residues are identified in Fig. 5C.

These conserved residues thus may be used to define the corresponding equivalent amino acid residues of B. amyloliquefaciens subtilisin in other carbonyl hydrolases such as thermitase derived from Thermoactinomyces. These two particular sequences are aligned in Fig. 5B to produce the maximum homology of conserved residues. As can be seen there are a number of insertions and deletions in the thermitase sequence as compared to B. amyloliquefaciens subtilisin. Thus, in thermitase the equivalent amino acid of Tyr217 in B. amyloliquefaciens subtilisin is the particular lysine shown beneath Tyr217.

In Fig. 5A, the equivalent amino acid at position 217 in B. amyloliquefaciens subtilisin is Tyr. Likewise,

in B. subtilis subtilisin position 217 is also occupied by Tyr but in B. licheniformis position 217 is occupied by Leu.

Thus, these particular residues in thermitase, and subtilisin from B. subtilisin and B. licheniformis may be substituted by a different amino acid to produce a mutant carbonyl hydrolase since they are equivalent in primary structure to Tyr217 in B. amyloliquefaciens subtilisin. Equivalent amino acids of course are not limited to those for Tyr217 but extend to any residue which is equivalent to a residue in B. amyloliquefaciens whether such residues are conserved or not.

Equivalent residues homologous at the level of tertiary structure for a precursor carbonyl hydrolase whose tertiary structure has been determined by x-ray crystallography, are defined as those for which the atomic coordinates of 2 or more of the main chain atoms of a particular amino acid residue of the precursor carbonyl hydrolase and B. amyloliquefaciens subtilisin (N on N, CA on CA, C on C, and O on O) are within 0.13nm and preferably 0.1nm after alignment. Alignment is achieved after the best model has been oriented and positioned to give the maximum overlap of atomic coordinates of non-hydrogen protein atoms of the carbonyl hydrolase in question to the B. amyloliquefaciens subtilisin. The best model is the crystallographic model giving the lowest R factor for experimental diffraction data at the highest resolution available.

$$\text{R factor} = \frac{\sum_h |Fo(h)| - |Fc(h)|}{\sum_h |Fo(h)|}$$

Equivalent residues which are functionally analogous to a specific residue of B. amyloliquefaciens subtilisin are defined as those amino acids of the precursor carbonyl hydrolases which may adopt a conformation such that they either alter, modify or contribute to protein structure, substrate binding or catalysis in a manner defined and attributed to a specific residue of the B. amyloliquefaciens subtilisin as described herein. Further, they are those residues of the precursor carbonyl hydrolase (for which a tertiary structure has been obtained by x-ray crystallography), which occupy an analogous position to the extent that although the main chain atoms of the given residue may not satisfy the criteria of equivalence on the basis of occupying a homologous position, the atomic coordinates of at least two of the side chain atoms of the residue lie with 0.13nm of the corresponding side chain atoms of B. amyloliquefaciens subtilisin. The three dimensional structures would be aligned as outlined above.

Some of the residues identified for substitution, insertion or deletion are conserved residues whereas others are not. In the case of residues which are not conserved, the replacement of one or more amino acids is limited to substitutions which produce a mutant which has an amino acid sequence that does not correspond to one found in nature. In the case of conserved residues, such replacements should not result in a naturally occurring sequence. The carbonyl hydrolase mutants of the present invention include the mature forms of carbonyl hydrolase mutants as well as the pro- and prepro-forms of such hydrolase mutants. The prepro-forms are the preferred construction since

this facilitates the expression, secretion and maturation of the carbonyl hydrolase mutants.

"Expression vector" refers to a DNA construct containing a DNA sequence which is operably linked to a suitable control sequence capable of effecting the expression of said DNA in a suitable host. Such control sequences include a promoter to effect transcription, an optional operator sequence to control such transcription, a sequence encoding suitable mRNA ribosome binding sites, and sequences which control termination of transcription and translation. The vector may be a plasmid, a phage particle, or simply a potential genomic insert. Once transformed into a suitable host, the vector may replicate and function independently of the host genome, or may, in some instances, integrate into the genome itself. In the present specification, "plasmid" and "vector" are sometimes used interchangeably as the plasmid is the most commonly used form of vector at present. However, the invention is intended to include such other forms of expression vectors which serve equivalent functions and which are, or become, known in the art.

The "host cells" used in the present invention generally are procaryotic or eucaryotic hosts which preferably have been manipulated by the methods disclosed in EPO Publication No. 0130756 to render

them incapable of secreting enzymatically active endoprotease. A preferred host cell for expressing subtilisin is the Bacillus strain BG2036 which is deficient in enzymatically active neutral protease and alkaline protease (subtilisin). The construction of strain BG2036 is described in detail in EPO Publicatin No. 0130756 and further described by Yang, M.Y., et al. (1984) J. Bacteriol. 160, 15-21. Other host cells for expressing subtilisin include Bacillus subtilis I168 (EPO Publication No. 0130756).

Host cells are transformed or transfected with vectors constructed using recombinant DNA techniques. Such transformed host cells are capable of either replicating vectors encoding the carbonyl hydrolase mutants or expressing the desired carbonyl hydrolase mutant. In the case of vectors which encode the pre or prepro form of the carbonyl hydrolase mutant, such mutants, when expressed, are typically secreted from the host cell into the host cell medium.

"Operably linked" when describing the relationship between two DNA regions simply means that they are functionally related to each other. For example, a presequence is operably linked to a peptide if it functions as a signal sequence, participating in the secretion of the mature form of the protein most probably involving cleavage of the signal sequence. A promoter is operably linked to a coding sequence if it controls the transcription of the sequence; a ribosome binding site is operably linked to a coding sequence if it is positioned so as to permit translation.

The genes encoding the naturally-occurring precursor carbonyl hydrolase may be obtained in accord with the

general methods described herein in EPO Publication No. 0130756.

Once the carbonyl hydrolase gene has been cloned, a number of modifications are undertaken to enhance the use of the gene beyond synthesis of the naturally-occurring precursor carbonyl hydrolase. Such modifications include the production of recombinant carbonyl hydrolases as disclosed in EPO Publication No. 0130756 and the production of carbonyl hydrolase mutants described herein.

The carbonyl hydrolase mutants of the present invention may be generated by site specific mutagenesis (Smith, M. (1985) Ann, Rev. Genet. 423; Zoeller, M.J., et al. (1982) Nucleic Acid Res. 10, 6487-6500), cassette mutagenesis (EPO Publication No. 0130756) or random mutagenesis (Shortle, D., et al. (1985) Genetics, 110, 539; Shortle, D., et al. (1986) Proteins: Structure, Function and Genetics, 1, 81; Shortle, D. (1986) J. Cell. Biochem, 30, 281; Alber, T., et al. (1985) Proc. Natl. Acad. of Sci., 82, 747; Matsumura, M., et al. (1985) J. Biochem., 260, 15298; Liao, H., et al. (1986) Proc. Natl. Acad. of Sci., 83 576) of the cloned precursor carbonyl hydrolase. Cassette mutagenesis and the random mutagenesis method disclosed herein are preferred.

The mutant carbonyl hydrolases expressed upon transformation of suitable hosts are screened for enzymes exhibiting one or more properties which are substantially different from the properties of the precursor carbonyl hydrolases, e.g., changes in substrate specificity, oxidative stability, thermal stability, alkaline stability, resistance to

proteolytic degradation, pH-activity profiles and the like.

A change in substrate specificity is defined as a difference between the kcat/Km ratio of the precursor carbonyl hydrolase and that of the hydrolase mutant. The kcat/Km ratio is a measure of catalytic efficienty. Carbonyl hydrolase mutants with increased or diminished kcat/Km ratios are described in the examples. Generally, the objective will be to secure a mutant having a greater (numerically large) kcat/Km ratio for a given substrate, thereby enabling the use of the enzyme to more efficiently act on a target substrate. A substantial change in kcat/Km ratio is preferably at least 2-fold increase or decrease. However, smaller increases or decreases in the ratio (e.g., at least 1.5-fold) are also considered substantial. An increase in kcat/Km ratio for one substrate may be accompanied by a reduction in kcat/Km ratio for another substrate. This is a shift in substrate specificity, and mutants exhibiting such shifts have utility where the precursor hydrolase is undesirable, e.g. to prevent undesired hydrolysis of a particular substrate in an admixture of substrates. Km and kcat are measured in accord with known procedures, as described in EPO Publication No. 0130756 or as described herein.

Oxidative stability is measured either by known procedures or by the methods described hereinafter. A substantial change in oxidative stability is evidenced by at least about 50% increase or decrease (preferably decrease) in the rate of loss of enzyme activity when exposed to various oxidizing conditions. Such oxidizing conditions are exposure to the organic

oxidant diperdodecanoic acid (DPDA) under the conditions described in the examples.

Alkaline stability is measured either by known procedures or by the methods described herein. A substantial change in alkaline stability is evidenced by at least about a 5% or greater increase or decrease (preferably increase) in the half life of the enzymatic activity of a mutant when compared to the precursor carbonyl hydrolase. In the case of subtilisins, alkaline stability was measured as a function of autoproteolytic degradation of subtilisin at alkaline pH, e.g. for example, 0.1M sodium phosphate, pH 12 at 25° or 30°C.

Thermal stability is measured either by known procedures or by the methods described herein. A substantial change in thermal stability is evidenced by at least about a 5% or greater increase or decrease (preferably increase) in the half-life of the catalytic activity of a mutant when exposed to a relatively high temperature and neutral pH as compared to the precursor carbonyl hydrolase. In the case of subtilisins, thermal stability is measured by the autoproteolytic degradation of subtilisin at elevated temperatures and neutral pH, e.g., for example 2mM calcium chloride, 50mM MOPS pH 7.0 at 59°C.

The inventors have produced mutant subtilisins containing the substitution of the amino acid residues of B. amyloliquefaciens subtilisin shown in Table I. The wild type amino acid sequence and DNA sequence of B. amyloliquefaciens subtilisin is shown in Fig. 1.

TABLE I

Residue	Replacement Amino Acid
Tyr21	F A
Thr22	C
Ser24	C
Asp32	Q S
Ser33	A T
Asp36	A G
Gly46	V
Ala48	E V R
Ser49	C L
Met50	C F V
Asn77	D
Ser87	C
Lys94	C
Val95	C
Leu96	D
Tyr104	A C D E F G H I K L M N P Q R S T V W
Ile107	V
Gly110	C R
Met124	I L
Asn155	A D H Q T
Glu156	Q S
Gly166	C E I L M P S T W Y
Gly169	C D E F H I K L M N P Q R T V W Y
Lys170	E R
Tyr171	F
Pro172	E Q
Phe189	A C D E G H I K L M N P Q R S T V W Y
Asp197	R A
Met199	I
Ser204	C R L P
Lys213	R T
Tyr217	A C D E F G H I K L M N P Q R S T V W
Ser221	A C

The different amino acids substituted are represented in Table I by the following single letter designations:

Amino acid or residue thereof	3-letter symbol	1-letter symbol
Alanine	Ala	A
Glutamate	Glu	E
Glutamine	Gln	Q
Aspartate	Asp	D
Asparagine	Asn	N
Leucine	Leu	L
Glycine	Gly	G
Lysine	Lys	K
Serine	Ser	S
Valine	Val	V
Arginine	Arg	R
Threonine	Thr	T
Proline	Pro	P
Isoleucine	Ile	I
Methionine	Met	M
Phenylalanine	Phe	F
Tyrosine	Tyr	Y
Cysteine	Cys	C
Tryptophan	Trp	W
Histidine	His	H

Except where otherwise indicated by context, wild-type amino acids are represented by the above three-letter symbols and replaced amino acids by the above single-letter symbols. Thus, if the methionine at residue 50 in B. amyloliquefaciens subtilisin is

replaced by phenylalanine, this mutation (mutant) may be designated Met50F or F50. Similar designations are used for multiple mutants.

In addition to the amino acids used to replace the residues disclosed in Table I, other replacements of amino acids at these residues are expected to produce mutant subtilisins having useful properties. These residues and replacement amino acids are shown in Table II.

TABLE II

Residue	Replacement Amino Acid(s)
Tyr-21	L
Thr22	K
Ser24	A
Asp32	
Ser33	G
Gly46	
Ala48	
Ser49	
Met50	L K I V
Asn77	D
Ser87	N
Lys94	R Q
Val95	L I
Tyr104	
Met124	K A
Ala152	C L I T M
Asn155	
Glu156	A T M L Y
Gly166	
Gly169	
Tyr171	K R E Q
Pro172	D N
Phe189	
Tyr217	
Ser221	
Met222	

Each of the mutant subtilisins in Table I contain the replacement of a single residue of the B. amyloliquefaciens amino acid sequence. These particular residues were chosen to probe the influence

of such substitutions on various properties of B. amyloliquefacien subtilisin.

Thus, the inventors have identified Met124 and Met222 as important residues which if substituted with another amino acid produce a mutant subtilisin with enhanced oxidative stability. For Met124, Leu and Ile are preferred replacement amino acids. Preferred amino acids for replacement of Met222 are disclosed in EPO Publication No. 0130756.

Various other specific residues have also been identified as being important with regard to substrate specificity. These residues include Tyr104, Ala152, Glu156, Gly166, Gly169, Phe189 and Tyr217 for which mutants containing the various replacement amino acids presented in Table I have already been made, as well as other residues presented below for which mutants have yet to be made.

The identification of these residues, including those yet to be mutated, is based on the inventors' high resolution crystal structure of B. amyloliquefaciens subtilisin to 1.8 A (see Table III), their experience with in vitro mutagenesis of subtilisin and the literature on subtilisin. This work and the x-ray crystal structures of subtilisin containing covalently bound peptide inhibitors (Robertus, J.D., et al. (1972) Biochemistry 11, 2439-2449), product complexes (Robertus, J.D., et al. (1972) Biochemistry 11, 4293-4303), and transition state analogs (Matthews, D.A., et al (1975) J. Biol. Chem. 250, 7120-7126; Poulos, T.L., et al. (1976) J. Biol. Chem. 251, 1097-1103), has helped in identifying an extended peptide binding cleft in subtilisin. This substrate binding cleft together with substrate is schematically

diagramemed in Fig. 2, according to the nomenclature of Schechter, I., et al. (1967) Biochem Bio. Res. Commun. 27, 157. The scissile bond in the substrate is identified by an arrow. The P and P' designations refer to the amino acids which are positioned respectively toward the amino or carboxy terminus relative to the scissle bond. The S and S' designations refer to subsites in the substrate binding cleft of subtilisin which interact with the corresponding substrate amino acid residues.

Atomic Coordinates for the Apoenzyme Form of B, Amyloliquefaciens Subtilisin to 1.8AResolution

1	ALA N	19.434	53.195	-21.756	1	ALA CA	19.811	51.774	-21.965
1	ALA C	18.731	50.925	-21.324	1	ALA O	18.374	51.197	-20.175
1	ALA CB	21.099	51.518	-21.183	2	GLN N	18.268	49.886	-22.841
2	GLN CA	17.219	49.008	-21.434	2	GLN C	17.875	47.706	-20.992
2	GLN O	18.765	47.165	-21.691	2	GLN CB	16.125	48.760	-22.449
2	GLN CG	15.328	47.985	-21.927	2	GLN CD	13.912	47.762	-22.930
2	GLN OE1	13.023	48.612	-22.867	2	GLN NE2	14.115	46.917	-23.926
3	SER N	17.477	47.205	-19.852	3	SER CA	17.950	45.868	-19.437
3	SER C	16.735	44.918	-19.490	3	SER O	15.590	45.352	-19.229
3	SER CB	18.588	45.838	-18.069	3	SER OG	17.682	46.218	-17.049
4	VAL N	16.991	43.646	-19.725	4	VAL CA	15.946	42.619	-19.639
4	VAL C	16.129	41.934	-18.290	4	VAL O	17.123	41.178	-18.886
4	VAL CB	16.008	41.622	-20.822	4	VAL CG1	14.874	40.572	-20.741
4	VAL CG2	16.837	42.266	-22.186	5	PRO N	15.239	42.186	-17.331
5	PRO CA	15.384	41.415	-16.827	5	PRO C	15.581	39.905	-16.249
5	PRO O	14.885	39.263	-17.146	5	PRO CB	14.150	41.880	-15.263
5	PRO CG	13.841	43.215	-15.921	5	PRO CD	14.844	42.986	-17.417
6	TYR N	16.363	39.240	-15.487	6	TYR CA	16.628	37.803	-15.715
6	TYR C	15.359	36.975	-15.528	6	TYR O	15.224	35.943	-14.235
6	TYR CB	17.824	37.323	-14.834	6	TYR CG	18.021	35.847	-15.855
6	TYR CD1	18.437	35.452	-16.346	6	TYR CD2	17.696	34.988	-14.871
6	TYR CE1	18.535	34.070	-16.653	6	TYR CE2	17.815	33.539	-14.379
6	TYR CZ	18.222	33.154	-15.628	6	TYR OH	18.312	31.838	-15.996
7	GLY N	14.464	37.362	-14.630	7	GLY CA	13.211	36.640	-14.376
7	GLY C	12.400	36.535	-15.670	7	GLY O	11.747	35.478	-15.883
8	VAL N	12.461	37.529	-16.541	8	VAL CA	11.777	37.523	-17.836
8	VAL C	12.363	36.433	-18.735	8	VAL O	11.639	35.716	-19.470
8	VAL CB	11.765	38.900	-18.567	8	VAL CG1	11.106	38.893	-19.943
8	VAL CG2	10.991	39.919	-17.733	9	SER N	13.661	36.318	-18.775
9	SER CA	14.419	35.342	-19.562	9	SER C	14.188	33.920	-18.965
9	SER O	14.112	33.814	-19.901	9	SER CB	15.926	35.632	-19.585
9	SER OG	16.162	36.747	-20.358	10	GLN N	14.115	33.887	-17.662
10	GLN CA	13.964	32.636	-16.876	10	GLN C	12.687	31.887	-17.277
10	GLN O	12.785	30.642	-17.413	10	GLN CB	14.125	32.885	-15.410
10	GLN CG	14.295	31.617	-14.588	10	GLN CD	14.486	31.911	-13.147
10	GLN OE1	14.356	33.068	-12.764	10	GLN NE2	14.552	30.960	-12.251
11	ILE N	11.625	32.575	-17.670	11	ILE CA	10.373	31.904	-18.182
11	ILE C	10.209	31.792	-19.605	11	ILE O	9.173	31.333	-20.180
11	ILE CB	9.132	32.669	-17.475	11	ILE CG1	9.046	34.117	-18.849
11	ILE CG2	9.162	32.655	-15.941	11	ILE CD1	7.588	34.648	-17.923
12	LYS N	11.272	32.185	-20.277	12	LYS CA	11.388	32.119	-21.722
12	LYS C	10.456	33.886	-22.522	12	LYS O	10.178	32.703	-23.686
12	LYS CB	11.257	30.646	-22.216	12	LYS CG	12.283	29.830	-21.423
12	LYS CD	12.543	28.517	-22.159	12	LYS CE	13.023	27.467	-21.166
12	LYS NZ	14.476	27.680	-20.935	13	ALA N	10.109	34.138	-21.991
13	ALA CA	9.325	35.198	-22.631	13	ALA C	10.826	35.716	-23.863
13	ALA O	9.338	35.804	-24.901	13	ALA CB	8.885	36.195	-21.565
14	PRO N	11.332	35.958	-23.893	14	PRO CA	11.985	36.430	-25.120
14	PRO C	11.786	35.557	-26.317	14	PRO O	11.778	36.847	-27.445
14	PRO CB	13.462	36.580	-24.692	14	PRO CG	13.328	36.978	-23.221
14	PRO CD	12.281	35.936	-22.758	15	ALA N	11.568	34.236	-26.129
15	ALA CA	11.379	33.458	-27.367	15	ALA C	10.082	33.795	-28.032
15	ALA O	10.808	33.718	-29.278	15	ALA CB	11.552	31.969	-27.662
16	LEU N	9.885	34.138	-27.248	16	LEU CA	7.791	34.558	-27.828
16	LEU C	7.912	35.925	-28.521	16	LEU O	7.342	36.126	-28.588
16	LEU CB	6.746	34.623	-26.698	16	LEU CG	5.798	33.465	-26.522
16	LEU CD1	5.881	33.236	-27.809	16	LEU CD2	6.694	32.287	-26.283
17	HIS N	8.665	36.828	-27.922	17	HIS CA	8.898	38.151	-28.538
17	HIS C	9.518	37.981	-29.898	17	HIS O	9.387	38.622	-30.856
17	HIS CB	9.708	39.188	-27.652	17	HIS CG	9.185	39.288	-26.262
17	HIS ND1	9.938	39.887	-25.272	17	HIS CD2	8.088	38.924	-25.694
17	HIS CE1	9.226	39.914	-24.144	17	HIS NE2	8.879	39.328	-24.381
18	SER N	10.443	37.833	-30.822	18	SER CA	11.189	36.739	-31.322

18	SER C	10.199	36.123	-32.363	18	SER O	10.567	36.112	-33.534
18	SER CB	12.311	35.799	-31.272	19	GLN CA	13.321	36.480	-33.399
19	GLN N	9.880	35.489	-31.963	19	GLN O	8.082	34.962	-32.878
19	GLN C	7.142	36.111	-33.303	19	GLN CG	6.297	35.972	-34.219
19	GLN CA	7.221	35.849	-32.280	19	GLN OE1	7.975	32.602	-31.823
19	GLN CD	6.923	31.797	-31.181	20	GLY N	9.719	33.833	-31.644
19	GLN NE2	7.362	30.892	-30.256	20	GLY C	7.205	37.223	-32.587
20	GLY CA	6.369	29.387	-32.869	21	TYR N	5.181	38.692	-31.880
20	GLY O	4.263	29.276	-32.215	21	TYR C	5.202	37.801	-30.761
21	TYR CA	4.116	27.931	-29.763	21	TYR CB	4.879	38.852	-28.928
21	TYR O	5.422	28.874	-27.756	21	TYR CD1	3.498	36.631	-29.443
21	TYR CG	2.973	31.784	-30.709	21	TYR CE1	3.795	36.332	-31.298
21	TYR CD2	3.650	34.794	-31.897	21	TYR CZ	3.306	35.797	-32.446
21	TYR CE2	3.193	34.261	-32.888	22	THR N	2.083	34.755	-33.867
21	TYR OH	1.801	36.241	-34.290	22	THR C	2.902	33.698	-35.288
22	THR CA	4.262	40.527	-27.129	22	THR CB	3.091	40.922	-36.244
22	THR O	3.287	41.725	-25.323	22	THR CG2	3.133	41.755	-37.611
22	THR OG1	4.319	42.487	-28.597	23	GLY CA	0.476	41.323	-38.229
23	GLY N	1.939	40.285	-26.493	23	GLY O	0.809	40.000	-25.562
23	GLY C	-0.197	41.691	-26.118	24	SER CA	-1.813	42.895	-25.330
24	SER N	-0.023	41.967	-27.371	24	SER O	-0.897	42.937	-28.812
24	SER C	-2.383	42.626	-27.864	25	ASN CA	-2.813	41.508	-28.168
24	SER CB	-0.734	43.120	-29.320	25	ASN O	0.563	43.632	-29.728
25	ASN N	-3.059	43.692	-27.515	26	VAL CA	-4.819	43.487	-27.393
25	ASN C	-5.015	42.875	-26.205	26	VAL O	-6.233	42.668	-26.190
25	ASN CB	-5.165	43.227	-28.705	26	VAL CG1	-4.968	44.178	-29.885
25	ASN OD1	-4.969	43.767	-31.083	27	LYS N	-4.747	45.461	-29.996
26	VAL N	-6.177	42.449	-25.292	27	LYS C	-4.674	41.479	-24.143
26	VAL C	-6.792	41.652	-22.987	27	LYS CB	-3.858	43.619	-22.699
26	VAL CB	-3.714	40.903	-23.821	27	LYS CD	-4.160	39.802	-22.548
26	VAL CG2	-3.898	39.576	-25.018	27	LYS NZ	-5.910	42.613	-22.301
27	LYS CA	-6.133	43.524	-21.175	28	VAL CA	-8.815	42.872	-19.841
27	LYS O	-6.605	41.873	-19.413	28	VAL O	-7.890	43.981	-21.169
27	LYS CG	-8.046	44.575	-22.490	28	VAL CG1	-9.321	43.302	-22.820
27	LYS CE	-10.304	45.497	-23.137	29	ALA N	-9.686	46.283	-24.264
28	VAL N	-6.818	43.462	-19.205	29	ALA C	-6.457	42.930	-17.897
28	VAL C	-4.798	43.959	-16.828	29	ALA CB	-6.209	45.893	-16.817
28	VAL CB	-2.926	42.666	-17.082	30	VAL CA	-2.466	42.185	-16.589
28	VAL CG2	-2.667	41.805	-19.173	30	VAL O	-3.484	43.527	-15.813
29	ALA CA	-5.747	44.330	-14.639	30	VAL CG1	-4.750	44.810	-13.553
29	ALA O	-6.666	42.845	-13.104	31	ILE N	-7.172	44.187	-14.101
29	ALA CB	-6.857	45.033	-13.072	31	ILE C	-5.146	44.962	-11.910
30	VAL N	-3.998	45.609	-10.681	31	ILE CB	-6.196	46.648	-10.878
30	VAL C	-1.886	45.810	-12.149	31	ILE CG2	-6.996	45.981	-10.998
30	VAL CB	-1.853	46.236	-13.307	32	ASP N	-4.514	44.515	-9.877
30	VAL CG2	-5.328	46.846	-8.679	32	ASP C	-4.348	44.933	-7.868
31	ILE CA	-3.825	43.915	-8.997	32	ASP CB	-4.497	43.776	-8.501
31	ILE O	-7.298	43.787	-9.798	32	ASP OD1	-7.278	44.838	-7.225
31	ILE CG1	-8.617	42.856	-9.717	33	SER N	-4.044	46.193	-7.227
31	ILE CD1	-2.944	46.467	-6.255	33	SER C	-3.871	47.889	-5.785
32	ASP CA	-4.197	48.418	-6.582	33	SER CB	-1.695	46.129	-7.092
32	ASP O	-8.483	48.782	-8.273	33	SER OG	0.834	44.592	-8.376
32	ASP CG	-8.081	46.429	-8.330	34	GLY N	-1.931	48.812	-5.394
32	ASP OD2	-1.898	49.897	-6.801	34	GLY C	-1.982	50.976	-3.868
33	SER CA	-1.706	52.186	-5.363	35	ILE N	-0.611	49.922	-3.939
33	SER O	0.535	50.025	-4.774	35	ILE C	-2.173	50.760	-7.884
33	SER OG	-2.295	51.726	-8.165	35	ILE CB	-1.838	51.648	-9.857
34	GLY CA	-0.144	50.831	-8.761	35	ILE CG2	-0.965	52.431	-10.102
34	GLY O	0.208	52.438	-10.095	36	ASP N	0.068	53.919	-11.263
35	ILE CA	-0.327	54.635	-11.744	36	ASP C	-0.842	51.604	-12.367
35	ILE O	-0.530	50.210	-12.097			1.169	51.741	-13.362
35	ILE CG1	-0.962	49.495	-13.424			1.816	54.293	-10.971
35	ILE CD1	2.359	55.638	-11.232			2.281	55.956	-12.702
36	ASP CA								

36	ASP O	3.804	55.471	-13.579
36	ASP CG	4.339	57.099	-10.806
36	ASP OD2	5.448	57.277	-10.263
37	SER CA	1.183	57.221	-14.512
37	SER O	2.565	58.303	-16.151
37	SER OG	-0.010	59.133	-13.079
38	SER CA	4.261	59.505	-14.487
38	SER O	6.543	59.251	-15.285
38	SER OG	5.376	59.865	-12.234
39	HIS CA	6.637	56.574	-15.291
39	HIS O	5.738	55.870	-17.419
39	HIS CG	8.014	54.609	-14.456
39	HIS CD2	8.769	54.345	-13.389
39	HIS NE2	9.986	53.910	-13.808
40	PRO CA	7.988	56.697	-18.831
40	PRO O	8.832	55.097	-20.578
40	PRO CG	10.053	57.405	-17.902
41	ASP N	8.461	54.320	-18.485
41	ASP OD1	10.325	51.395	-20.429
41	ASP CB	9.799	52.239	-18.224
41	ASP C	7.311	52.163	-18.839
42	LEU N	6.185	52.803	-18.558
42	LEU C	3.924	52.907	-19.376
42	LEU CB	4.421	52.158	-17.008
42	LEU CD1	4.535	51.546	-14.581
43	LYS N	3.018	52.135	-19.946
43	LYS C	0.637	52.156	-20.018
43	LYS CB	2.021	52.389	-22.169
43	LYS CD	0.998	52.862	-24.339
43	LYS NZ	0.337	51.757	-26.418
44	VAL CA	-1.407	52.639	-18.765
44	VAL O	-2.623	53.906	-20.434
44	VAL CG1	-2.724	52.941	-16.582
45	ALA N	-3.494	51.951	-19.871
45	ALA C	-5.041	52.507	-20.053
45	ALA CB	-4.031	50.580	-21.389
46	GLY CA	-7.082	52.837	-18.001
46	GLY O	-5.938	52.006	-16.035
47	GLY CA	-8.014	52.246	-14.388
47	GLY O	-9.988	53.481	-14.185
48	ALA CA	-10.255	52.970	-11.382
48	ALA O	-9.066	51.720	-9.725
49	SER N	-10.149	53.567	-9.037
49	SER C	-10.947	52.986	-6.783
49	SER CB	-9.092	54.588	-7.029
50	MET N	-10.835	52.007	-5.932
50	MET C	-11.463	51.962	-3.561
50	MET CB	-12.012	50.018	-4.996
50	MET SD	-13.460	49.889	-7.256
51	VAL N	-10.427	52.700	-3.422
51	VAL C	-10.630	54.562	-2.987
51	VAL CB	-8.443	53.155	-2.008
51	VAL CG2	-7.764	51.815	-2.302
52	PRO CA	-12.372	55.933	-0.821
52	PRO O	-11.771	58.220	-0.925
52	PRO CG	-13.583	54.183	0.085
53	SER N	-10.442	56.986	0.299
53	SER C	-8.428	58.265	-0.326
53	SER CB	-9.004	57.707	2.069
54	GLU N	-8.254	57.523	-1.393
54	GLU C	-7.767	57.303	-3.785
54	GLU CB	-6.134	56.595	-2.156
54	GLU CD	[illegible]	[illegible]	-0.070

36	ASP CB	3.712	55.720	-10.516
36	ASP OD1	3.755	57.974	-11.629
37	SER N	1.304	56.822	-13.111
37	SER C	2.377	58.895	-14.949
37	SER CB	-0.093	58.049	-14.788
38	SER N	3.163	58.614	-14.081
38	SER C	5.466	58.705	-14.992
38	SER CB	4.742	60.435	-13.398
39	HIS N	5.454	57.390	-14.892
39	HIS C	6.681	56.601	-16.778
39	HIS CB	6.637	55.203	-14.515
39	HIS ND1	8.795	54.356	-15.561
39	HIS CE1	9.970	53.930	-15.130
40	PRO N	7.007	56.836	-17.387
40	PRO C	8.156	55.280	-19.357
40	PRO CB	9.247	57.533	-19.161
40	PRO CD	8.988	57.452	-16.776
41	ASP OD2	11.148	58.399	-18.668
41	ASP CG	10.473	51.307	-19.211
41	ASP CA	8.665	52.959	-10.966
41	ASP O	7.396	50.947	-18.977
42	LEU CA	4.892	52.147	-18.466
42	LEU O	3.993	54.163	-19.490
42	LEU CG	5.182	51.363	-15.946
42	LEU CD2	5.273	49.877	-16.350
43	LYS CA	1.893	52.685	-20.721
43	LYS O	0.504	50.920	-19.820
43	LYS CG	0.685	52.436	-22.910
43	LYS CE	-0.180	52.584	-25.260
44	VAL N	-0.191	53.835	-19.490
44	VAL C	-2.571	52.887	-19.731
44	VAL CB	-1.480	53.351	-17.383
44	VAL CG2	-0.197	53.194	-16.553
45	ALA CA	-6.619	51.977	-20.810
45	ALA O	-6.703	53.085	-20.703
46	GLY N	-5.910	52.356	-18.768
46	GLY C	-6.987	52.443	-16.538
47	GLY N	-8.092	52.658	-15.793
47	GLY C	-9.179	52.757	-13.572
48	ALA N	-9.221	52.446	-12.330
48	ALA C	-9.790	52.675	-9.968
48	ALA CB	-11.558	52.100	-11.617
49	SER CA	-9.752	53.355	-7.652
49	SER O	-11.972	53.677	-6.988
49	SER OG	-8.879	54.255	-5.650
50	MET CA	-11.852	51.549	-4.974
50	MET O	-11.997	51.398	-2.575
50	MET CG	-11.912	49.463	-6.389
50	MET CE	-12.808	50.111	-8.983
51	VAL CA	-9.968	53.170	-2.867
51	VAL O	-10.237	55.437	-2.682
51	VAL CG1	-7.892	53.579	-0.631
52	PRO N	-11.621	54.693	-1.056
52	PRO C	-11.490	57.123	-0.440
52	PRO CB	-13.488	55.594	0.244
52	PRO CD	-12.364	53.620	-0.175
53	SER CA	-9.538	57.982	0.602
53	SER O	-7.679	59.224	-0.038
53	SER OG	-8.256	56.521	2.127
54	GLU CA	-7.206	57.648	-2.621
54	GLU O	-7.533	56.243	-4.379
54	GLU CG	-5.289	56.959	-0.927
54	GLU OE1	-1.665	55.694	-1.968

54	GLN OE2	-3.908	55.777	0.271
55	THR CA	-9.433	58.121	-5.441
55	THR B	-9.433	57.919	-7.810
55	THR OG1	-9.885	60.510	-5.418
56	ASN N	-7.682	58.403	-6.877
56	ASN OD1	-5.875	58.967	-10.337
56	ASN CB	-5.898	59.694	-8.208
56	ASN C	-6.812	57.094	-8.305
56	ASN C	-6.362	56.261	-9.258
57	PRO N	-7.384	56.433	-10.272
57	PRO CD	-5.679	54.961	-9.332
57	PRO CA	-3.589	54.128	-8.945
57	PRO O	-2.747	56.577	-11.222
58	PHE CA	-0.635	57.497	-10.680
58	PHE O	-3.983	56.968	-13.357
58	PHE CG	-5.211	57.638	-13.459
58	PHE CD2	-6.194	57.895	-16.276
58	PHE CE2	-2.844	57.119	-8.998
59	GLN N	-0.807	56.483	-7.808
59	GLN C	-1.862	58.668	-7.889
59	GLN CB	-1.798	60.157	-5.150
59	GLN CD	-2.959	59.685	-4.742
59	GLN NE2	0.851	54.792	-6.304
60	ASP CA	2.827	55.550	-5.231
60	ASP O	2.077	52.538	-6.380
60	ASP CG	2.915	51.841	-7.830
60	ASP OD2	-1.364	57.747	-2.347
61	ASN ND2	-0.848	57.678	-2.399
61	ASN CG	1.557	55.734	-2.700
61	ASN CA	2.933	54.862	-0.902
61	ASN O	2.877	52.348	-1.709
62	ASN CA	4.951	51.313	-1.770
62	ASN O	2.371	50.103	-0.697
62	ASN CG	2.622	50.208	0.601
62	ASN ND2	5.189	51.696	-4.709
63	SER CA	5.593	49.790	-6.269
63	SER O	6.871	50.698	-3.418
63	SER OG	3.994	48.859	-4.935
64	HIS CA	3.861	46.974	-7.108
64	HIS O	3.144	46.821	-3.726
64	HIS CG	4.854	45.194	-3.135
64	HIS CD2	3.556	43.920	-3.368
64	HIS NE2	1.552	48.264	-7.838
65	GLY CA	2.238	48.878	-10.134
65	GLY O	4.864	50.117	-9.956
66	THR CA	5.333	48.789	-11.461
66	THR O	3.637	52.425	-9.406
66	THR OG1	5.685	48.463	-9.274
67	HIS N	6.891	46.141	-10.143
67	HIS C	7.308	47.871	-8.864
67	HIS CB	8.590	44.907	-8.276
67	HIS ND1	9.857	44.491	-8.299
67	HIS CE1	9.892	45.749	-9.731
68	VAL N	3.854	44.868	-11.748
68	VAL C	2.939	44.252	-9.386
68	VAL CB	3.319	43.705	-8.888
68	VAL CG2	3.837	44.668	-13.429
69	ALA CA	4.828	45.913	-15.965
69	ALA O	5.348	48.782	-13.914
70	GLY N	7.846	45.378	-15.821
70	GLY C	6.820	44.431	-14.138
71	THR N	8.224	42.506	-15.543
71	THR C	7.119	42.878	-13.191
71	THR CB	-8.571	38.291	-6.249
71	THR CG2	-8.764	38.139	-8.779
72	ASN HD2	-10.586	39.288	-5.383
72	ASN CG	-11.432	39.143	-6.817
72	ASN CA	-6.938	41.179	-9.881
72	ASN O	-5.273	39.925	-9.555
73	PRO CG	-6.762	38.425	-8.288
73	PRO CB	-5.184	36.866	-7.478
73	PRO C	-7.123	35.257	-11.177
74	PHE N	-0.644	34.178	-10.235
74	PHE C	-4.381	35.882	-9.966
74	PHE CB	-3.998	36.262	-10.491
74	PHE CD1	-1.712	37.129	-10.253
74	PHE CE1	-2.943	37.582	-12.423
74	PHE CZ	-3.756	35.788	-14.059
75	GLN CA	-6.722	35.255	-14.928
75	GLN O	-5.949	35.939	-15.051
75	GLN CB	-1.172	37.583	-7.934
75	GLN CG	-1.639	36.883	-6.115
75	GLN OE1	-0.942	39.261	-6.834
76	ASP N	-1.604	41.288	-4.836
76	ASP C	0.418	35.895	-7.211
76	ASP CB	1.631	35.267	-5.090
76	ASP OD1	1.396	33.744	-7.188
77	ASN N	1.746	32.337	-5.190
77	ASN OD1	0.959	35.265	-3.950
77	ASN CB	0.666	38.566	-2.875
77	ASN C	0.531	36.401	-1.784
77	ASN C	2.291	34.632	-1.948
78	ASN N	2.218	33.434	-2.468
78	ASN C	4.124	31.893	-2.479
78	ASN CB	1.783	31.319	-1.421
78	ASN OD1	2.633	49.877	-1.343
79	SER N	4.152	32.184	-3.761
79	SER C	5.871	30.256	-5.209
79	SER CB	6.523	31.958	-4.812
80	HIS N	4.202	49.475	-6.639
80	HIS C	3.366	47.759	-6.261
80	HIS CB	3.184	47.501	-3.747
80	HIS ND1	2.187	45.247	-4.241
80	HIS CE1	2.416	43.966	-4.854
81	GLY N	2.287	48.428	-6.587
81	GLY C	2.392	48.636	-9.837
82	VAL CA	3.233	49.659	-8.832
82	VAL O	5.889	49.009	-10.291
82	VAL CG1	4.744	51.511	-9.647
83	ALA N	5.536	52.078	-10.849
83	ALA C	6.783	47.341	-9.458
83	ALA CB	6.649	45.638	-11.150
84	GLY CA	8.595	66.275	-8.168
84	GLY O	9.904	46.678	-8.876
85	THR N	10.678	45.514	-8.106
85	THR C	6.142	44.687	-10.266
85	THR CB	4.114	43.962	-12.535
85	THR CG2	1.960	63.260	-10.820
86	ASN HD2	3.373	66.869	-12.113
86	ASN CG	6.193	44.390	-14.611
86	ASN CA	2.332	47.851	-13.386
86	ASN O	6.595	46.005	-14.670
87	PRO CG	7.604	45.154	-16.119
87	PRO CB	7.177	43.019	-14.646
87	PRO C	6.682	41.828	-16.695
88	PHE N	8.191	42.592	-12.390

71	THR	CG2	7.274	48.383	-13.596
72	VAL	CA	3.976	42.491	-16.484
72	VAL	B	4.341	42.380	-18.868
72	VAL	CG1	1.512	42.498	-17.178
73	ALA	N	4.504	44.417	-17.888
73	ALA	C	5.433	46.333	-19.355
73	ALA	CB	3.187	45.441	-19.433
74	ALA	CA	7.478	47.591	-18.959
74	ALA	B	7.959	46.640	-21.054
75	LEU	N	7.658	48.784	-21.839
75	LEU	C	9.192	48.568	-22.966
75	LEU	CB	7.568	50.471	-22.809
75	LEU	CD1	6.879	52.436	-22.380
76	ASN	N	9.147	48.103	-24.169
76	ASN	OD1	10.950	45.840	-27.928
76	ASN	CB	10.810	46.651	-25.988
76	ASN	C	10.783	49.848	-25.643
77	ASN	N	11.804	49.664	-25.071
77	ASN	N	13.707	51.829	-25.348
77	ASN	C	11.335	52.876	-25.117
77	ASN	CB	12.032	51.346	-22.917
77	ASN	OD1	14.125	52.267	-25.164
78	SER	N	15.818	52.742	-23.436
78	SER	C	15.985	53.941	-25.587
78	SER	CB	14.858	52.565	-22.529
79	ILE	N	14.617	51.683	-20.230
79	ILE	C	14.471	54.174	-20.697
79	ILE	CB	14.997	55.320	-21.612
79	ILE	CG2	14.995	51.768	-18.981
80	GLY	N	14.612	49.448	-18.219
80	GLY	C	13.513	48.766	-17.980
81	VAL	N	12.511	46.919	-19.217
81	VAL	C	13.801	46.755	-16.677
81	VAL	CB	11.638	47.261	-16.231
81	VAL	CG2	11.312	45.820	-20.256
82	LEU	CA	10.858	43.356	-18.600
82	LEU	B	11.430	43.568	-22.366
82	LEU	CG	12.359	42.675	-23.192
82	LEU	CD2	8.133	43.321	-19.114
83	GLY	CA	8.946	41.822	-21.826
83	GLY	B	6.973	39.807	-19.888
84	VAL	CA	6.424	39.472	-22.194
84	VAL	D	5.680	37.677	-19.557
84	VAL	CG1	5.156	40.926	-21.024
85	ALA	N	4.213	42.683	-22.396
85	ALA	C	2.846	40.663	-21.748
85	ALA	CB	5.413	40.635	-23.285
86	PRO	CA	4.291	46.605	-23.849
86	PRO	D	7.830	43.466	-24.546
86	PRO	CG	3.548	44.676	-24.769
87	SER	N	1.103	45.132	-24.897
87	SER	C	2.401	44.777	-26.927
87	SER	CB	1.017	44.564	-23.742
88	ALA	N	-0.273	44.353	-23.084
88	ALA	CA	-0.174	46.717	-22.435
88	ALA	B	-4.146	47.102	-24.280
89	SER	OG	-3.801	46.867	-22.227
89	SER	CA	-3.793	45.864	-20.209
89	SER	D	-2.378	47.667	-18.593
90	LEU	CA	-3.582	49.604	-18.215
90	LEU	D	-0.233	47.851	-17.174
90	LEU	CG	1.160	48.524	-17.047
90	LEU	CD2	-5.258	48.478	-16.137
91	TYR	CA	4.930	42.887	-15.427
72	VAL	N	4.312	43.984	-17.831
72	VAL	C	2.516	42.867	-16.885
72	VAL	CB	2.142	42.327	-14.723
72	VAL	CG2	4.587	45.891	-19.167
73	ALA	CA	5.862	47.188	-20.216
73	ALA	D	6.544	46.629	-18.635
74	ALA	N	7.740	47.648	-20.342
74	ALA	C	8.653	47.446	-17.925
74	ALA	CB	7.812	48.968	-22.456
75	LEU	CA	10.162	48.758	-22.253
75	LEU	D	6.123	50.913	-22.379
75	LEU	CG	5.096	50.442	-23.485
75	LEU	CD2	12.385	46.432	-26.384
76	ASN	ND2	11.195	46.274	-26.802
76	ASN	CG	10.359	47.738	-24.938
76	ASN	CA	10.157	49.479	-26.619
76	ASN	D	12.220	50.957	-25.681
77	ASN	CA	14.364	49.979	-25.313
77	ASN	D	11.250	52.827	-23.616
77	ASN	CG	10.294	52.741	-23.825
77	ASN	ND2	15.513	52.614	-24.986
78	SER	CA	16.982	53.871	-23.164
78	SER	D	15.926	53.878	-26.999
78	SER	OG	15.155	52.784	-21.120
79	ILE	CA	13.843	50.841	-28.679
79	ILE	D	12.945	54.832	-28.814
79	ILE	CG1	12.135	55.176	-28.155
79	ILE	CD1	14.476	58.948	-17.913
80	GLY	CA	15.719	48.994	-18.544
80	GLY	D	13.411	47.286	-18.041
81	VAL	CA	12.260	47.739	-20.117
81	VAL	D	14.830	47.884	-15.573
81	VAL	CG1	12.126	45.645	-19.216
82	LEU	N	10.390	44.828	-19.510
82	LEU	C	12.206	44.219	-21.229
82	LEU	CB	10.796	44.657	-23.223
82	LEU	CD1	9.131	44.180	-19.816
83	GLY	N	8.827	42.811	-19.925
83	GLY	C	7.272	41.112	-19.283
84	VAL	N	6.164	40.830	-21.140
84	VAL	C	6.256	38.920	-18.841
84	VAL	CB	7.190	38.507	-17.705
84	VAL	CG2	4.217	41.196	-22.158
85	ALA	CA	3.260	43.601	-22.838
85	ALA	D	5.248	43.186	-23.859
86	PRO	N	4.321	45.371	-23.947
86	PRO	C	6.822	44.784	-23.813
86	PRO	CB	6.377	42.648	-23.636
86	PRO	CD	2.489	45.324	-25.529
87	SER	CA	8.162	45.513	-25.619
87	SER	B	3.591	45.143	-27.583
87	SER	OG	-0.163	43.510	-21.828
88	ALA	CB	-0.898	45.717	-22.690
88	ALA	C	-2.219	45.691	-22.678
89	SER	N	-4.343	46.983	-22.898
89	SER	CB	-3.136	46.780	-20.727
89	SER	C	-2.446	47.656	-20.037
90	LEU	N	-3.483	48.438	-17.864
90	LEU	C	-0.951	48.273	-18.426
90	LEU	CB	-0.826	46.341	-17.219
90	LEU	CD1	-4.264	47.964	-16.938
91	TYR	N	-4.873	48.758	-14.685
91	TYR	C			

91	TYR B	-4.496	47.749	-14.823
91	TYR CG	-7.894	48.237	-17.741
91	TYR CD2	-7.971	49.275	-18.149
91	TYR CE2	-8.315	49.421	-19.492
91	TYR OH	-8.182	48.752	-21.764
92	ALA CA	-6.949	50.199	-12.787
92	ALA O	-6.723	50.898	-12.050
93	VAL N	-5.959	48.993	-11.329
93	VAL C	-6.708	49.814	-8.899
93	VAL CB	-7.957	47.555	-10.613
93	VAL CG2	-8.195	47.378	-12.872
94	LYS CA	-6.378	50.464	-6.999
94	LYS O	-8.458	50.480	-5.783
94	LYS CG	-5.394	52.320	-5.467
94	LYS CE	-4.399	54.208	-4.199
95	VAL N	-6.909	49.071	-5.026
95	VAL C	-6.919	48.499	-2.568
95	VAL CB	-8.184	47.038	-4.319
95	VAL CG2	-6.980	46.180	-4.332
96	LEU CA	-4.782	49.183	-1.486
96	LEU O	-3.942	51.121	-2.336
96	LEU CG	-3.593	46.799	-2.072
96	LEU CD2	-4.489	46.082	-1.045
97	GLY CA	-3.890	52.307	0.287
97	GLY O	-1.619	51.463	0.165
98	ALA CB	-0.428	55.478	1.518
98	ALA C	0.188	53.118	1.917
99	ASP N	-0.584	52.573	2.912
99	ASP OD1	-2.730	58.902	4.083
99	ASP CB	-0.648	51.603	5.175
99	ASP O	0.166	50.165	3.320
100	GLY N	-0.424	49.883	2.168
100	GLY C	-1.528	47.651	2.002
101	SER N	-2.342	48.128	2.908
101	SER C	-4.759	47.894	2.532
101	SER CB	-3.716	47.447	4.817
102	GLY N	-5.821	47.892	2.577
102	GLY C	-8.164	46.536	2.528
103	GLN N	-9.377	47.858	2.498
103	GLN C	-10.963	45.232	2.022
103	GLN CB	-11.671	47.307	3.274
103	GLN CD	-12.368	49.104	4.915
103	GLN NE2	-13.419	49.197	4.112
104	TYR CA	-12.868	43.126	1.588
104	TYR O	-12.939	43.276	-0.687
104	TYR CG	-11.629	40.829	2.472
104	TYR CD2	-10.379	40.959	1.860
104	TYR CE2	-9.352	40.057	2.171
104	TYR OH	-8.481	38.191	3.324
105	SER CA	-14.877	45.164	-0.834
105	SER B	-14.759	45.935	-2.258
105	SER OG	-15.289	47.039	1.450
106	TRP CA	-12.621	47.391	-1.948
106	TRP B	-12.821	46.648	-4.245
106	TRP CG	-11.645	49.111	-8.206
106	TRP CD2	-10.658	49.812	8.581
106	TRP CE2	-11.359	50.573	1.561
106	TRP CZ2	-10.671	51.318	2.580
106	TRP CH2	-9.293	51.291	2.455
107	ILE CA	-10.765	44.250	-3.325
107	ILE B	-11.695	43.474	-5.398
107	ILE CG1	-8.634	43.784	-1.996
107	ILE CD1	-8.283	42.998	-0.627
91	TYR CB	-6.686	48.893	-16.914
91	TYR CD1	-6.595	47.415	-18.755
91	TYR CE1	-6.985	47.872	-20.898
91	TYR CZ	-7.796	48.582	-20.463
92	ALA N	-4.895	49.958	-14.104
92	ALA C	-5.823	50.833	-11.903
92	ALA CB	-3.997	51.621	-12.488
93	VAL CA	-7.183	48.854	-10.325
93	VAL O	-6.181	47.993	-8.372
93	VAL CG1	-9.213	47.488	-9.725
94	LYS N	-6.987	50.217	-8.327
94	LYS C	-7.331	49.985	-5.894
94	LYS CB	-6.051	51.976	-6.818
94	LYS CD	-4.868	53.785	-5.582
94	LYS NZ	-3.735	55.544	-4.387
95	VAL CA	-7.646	48.457	-3.920
95	VAL O	-7.425	48.156	-1.581
95	VAL CG1	-8.868	46.852	-5.419
96	LEU N	-5.676	48.974	-2.604
96	LEU C	-4.331	50.559	-1.321
96	LEU CB	-3.589	48.241	-1.573
96	LEU CD1	-2.207	46.184	-2.163
97	GLY N	-4.326	50.975	-0.886
97	GLY C	-2.363	52.437	0.385
98	ALA N	-1.954	53.648	0.758
98	ALA CA	-0.563	54.868	0.965
98	ALA O	1.393	52.921	1.663
99	ASP OD2	-2.631	51.842	6.151
99	ASP CG	-2.883	51.131	5.040
99	ASP CA	0.181	51.610	3.855
99	ASP O	0.735	49.313	4.829
100	GLY CA	-0.343	48.521	1.615
100	GLY O	-1.649	46.512	1.479
101	SER CA	-3.542	47.388	3.315
101	SER O	-4.758	48.972	1.907
101	SER OG	-4.411	48.634	5.289
102	GLY CA	-7.877	47.422	1.896
102	GLY O	-7.888	45.631	3.830
103	GLN CA	-10.535	46.297	3.820
103	GLN	-10.779	45.482	0.817
103	GLN CG	-11.368	48.805	4.586
103	GLN OE1	-12.159	49.816	5.982
104	TYR N	-11.611	46.141	2.451
104	TYR C	-13.031	43.690	0.473
104	TYR CB	-12.697	41.866	2.143
104	TYR CD1	-11.819	39.789	3.377
104	TYR CE1	-10.805	38.885	3.787
104	TYR CZ	-9.564	39.822	3.081
105	SER N	-13.909	44.572	0.903
105	SER C	-14.172	45.920	-1.159
105	SER CB	-15.880	46.121	0.601
106	TRP N	-13.879	46.625	-0.834
106	TRP C	-11.895	46.436	-3.012
106	TRP CB	-11.321	48.254	-1.355
106	TRP CD1	-12.862	49.524	0.264
106	TRP NE1	-12.691	50.358	1.360
106	TRP CE3	-9.275	49.852	0.576
106	TRP CZ3	-8.868	50.563	1.525
107	ILE N	-11.339	45.330	-2.681
107	ILE C	-11.955	43.596	-4.190
107	ILE CB	-9.946	43.183	-2.523
107	ILE CG2	-9.632	41.930	-3.381
108	ILE N	-12.994	43.292	-3.577

108	ILE CA	-14.114	42.722	-4.321
108	ILE B	-14.894	43.328	-6.552
108	ILE CG1	-14.726	41.077	-2.682
108	ILE CD1	-15.452	40.865	-1.131
109	ASN CA	-15.284	46.018	-5.916
109	ASN B	-14.660	46.272	-8.235
109	ASN CG	-16.528	47.600	-4.359
109	ASN ND2	-16.633	48.447	-3.442
110	GLY CA	-11.952	45.917	-7.865
110	GLY B	-11.929	44.929	-10.034
111	ILE CA	-12.603	42.334	-9.099
111	ILE B	-13.921	42.384	-11.148
111	ILE CG1	-11.421	40.581	-7.655
111	ILE CD1	-11.588	39.786	-6.336
112	GLU CA	-16.118	43.376	-10.846
112	GLU O	-16.467	44.130	-12.246
112	GLU CG	-17.847	42.917	-8.135
112	GLU OE1	-19.841	40.866	-8.816
113	TRP N	-15.096	45.403	-10.971
113	TRP C	-14.076	45.643	-13.140
113	TRP CB	-13.882	47.553	-11.434
113	TRP CD1	-14.168	49.736	-12.681
113	TRP NE1	-13.597	50.443	-13.723
113	TRP CE3	-11.451	47.645	-13.809
113	TRP CZ3	-10.618	47.899	-14.879
114	ALA N	-13.089	44.801	-12.832
114	ALA C	-13.199	43.179	-14.752
114	ALA CB	-11.299	43.192	-13.140
115	ILE CA	-15.070	41.648	-14.897
115	ILE O	-16.077	42.225	-17.070
115	ILE CG1	-15.218	39.836	-13.843
115	ILE CD1	-16.004	39.411	-11.743
116	ALA CA	-17.390	44.440	-16.850
116	ALA O	-17.323	45.255	-18.343
117	ASN N	-15.423	45.390	-17.122
117	ASN C	-13.827	44.974	-19.034
117	ASN CB	-13.615	46.958	-17.426
117	ASN OD1	-14.565	49.882	-17.773
118	ASN N	-14.223	43.725	-18.967
118	ASN C	-12.260	42.444	-19.843
118	ASN CB	-14.247	42.863	-21.279
118	ASN OD1	-16.510	42.321	-20.759
119	MET N	-11.686	42.580	-18.675
119	MET C	-10.025	40.734	-18.928
119	MET CB	-9.810	42.661	-17.055
119	MET SD	-8.788	44.943	-17.526
120	ASP N	-8.984	40.637	-19.584
120	ASP C	-7.822	38.390	-18.856
120	ASP CB	-7.555	39.156	-21.236
120	ASP OD1	-7.881	40.706	-23.084
121	VAL N	-7.021	39.117	-18.115
121	VAL C	-6.296	39.534	-15.706
121	VAL CB	-4.755	38.587	-17.696
121	VAL CG2	-4.787	37.916	-18.846
122	ILE CA	-6.248	39.799	-13.397
122	ILE B	-4.829	38.812	-12.469
122	ILE CG1	-8.686	40.392	-13.063
122	ILE CD1	-9.976	39.788	-12.393
123	ASN CA	-3.145	39.854	-11.232
123	ASN B	-3.788	41.631	-9.833
123	ASN CG	-0.892	40.848	-10.777
123	ASN ND2	-0.346	40.747	-9.728
124	MET CA	-3.658	39.973	-7.638
108	ILE C	-14.839	43.694	-5.986
108	ILE CB	-15.246	42.265	-3.328
108	ILE CG2	-16.568	42.824	-4.895
109	ASN N	-14.751	44.958	-4.981
109	ASN C	-14.232	46.867	-7.884
109	ASN CB	-15.280	47.359	-5.287
109	ASN OD1	-17.455	46.695	-4.646
110	GLY N	-12.951	45.988	-6.774
110	GLY C	-12.108	44.712	-8.812
111	ILE N	-12.379	43.539	-8.246
111	ILE C	-13.859	42.568	-9.942
111	ILE CB	-12.734	40.948	-8.364
111	ILE CG2	-13.122	39.791	-9.347
112	GLU N	-14.893	43.875	-9.288
112	GLU C	-15.872	44.347	-11.171
112	GLU CB	-17.229	43.899	-9.141
112	GLU CD	-18.724	41.826	-8.685
112	GLU OE2	-19.123	41.928	-9.866
113	TRP CA	-14.756	46.408	-12.888
113	TRP O	-14.319	45.932	-14.332
113	TRP CG	-13.486	48.556	-12.481
113	TRP CD2	-12.441	48.552	-13.463
113	TRP CE2	-12.545	49.761	-14.215
113	TRP CZ2	-11.696	50.845	-15.274
113	TRP CH2	-10.752	49.874	-15.683
114	ALA CA	-12.333	44.865	-13.874
114	ALA B	-12.983	43.874	-15.978
115	ILE N	-14.174	42.548	-14.119
115	ILE C	-15.928	42.485	-15.856
115	ILE CB	-16.880	40.840	-13.922
115	ILE CG2	-17.151	40.168	-14.755
116	ALA N	-16.534	43.527	-15.267
116	ALA C	-16.706	45.069	-17.278
116	ALA CB	-18.811	45.518	-15.151
117	ASN CA	-16.553	45.967	-18.139
117	ASN O	-12.997	45.436	-19.828
117	ASN CG	-14.400	48.177	-16.939
117	ASN ND2	-14.931	48.249	-15.736
118	ASN CA	-13.760	42.642	-19.832
118	ASN O	-11.617	42.309	-20.932
118	ASN CG	-15.737	43.060	-21.395
118	ASN ND2	-16.136	44.096	-22.133
119	MET CA	-10.232	42.222	-18.478
119	MET O	-10.888	39.838	-18.759
119	MET CG	-9.880	43.883	-16.582
119	MET CE	-9.982	46.861	-18.263
120	ASP CA	-8.488	39.118	-20.830
120	ASP O	-8.838	37.189	-18.690
120	ASP CG	-8.237	39.730	-22.454
120	ASP OD2	-9.327	39.135	-22.739
121	VAL CA	-6.224	38.601	-16.974
121	VAL O	-6.284	40.788	-15.989
121	VAL CG1	-3.758	38.176	-16.427
122	ILE N	-6.318	38.978	-14.598
122	ILE C	-5.820	39.262	-12.627
122	ILE CB	-7.476	39.604	-12.666
122	ILE CG2	-7.221	39.883	-10.954
123	ASN N	-4.263	40.222	-12.110
123	ASN C	-3.502	40.604	-9.861
123	ASN CB	-1.828	40.478	-11.697
123	ASN OD1	-0.063	38.990	-11.018
124	MET N	-3.458	39.604	-8.832
124	MET C	-2.423	39.603	-6.614

124	MET O	-2.306	38.308	-6.890	124	MET CB	-6.943	39.287	-6.898
124	MET CG	-6.198	40.882	-7.473	124	MET SD	-7.885	39.472	-8.450
124	MET CE	-7.949	38.095	-7.942	125	SER N	-1.454	40.496	-6.582
125	SER CA	-8.193	40.287	-8.769	125	SER C	-0.422	40.712	-6.326
125	SER O	0.238	41.617	-9.805	125	SER CB	1.021	41.027	-6.328
125	SER OG	1.444	40.496	-7.875	126	LEU N	-1.433	40.073	-3.775
126	LEU CA	-1.662	40.347	-2.389	126	LEU C	-2.438	39.096	-1.807
126	LEU O	-2.864	38.136	-2.529	126	LEU CB	-2.791	41.868	-2.610
126	LEU CG	-3.988	41.447	-3.333	126	LEU CD1	-3.278	41.131	-3.578
126	LEU CD2	-5.179	42.760	-4.073	127	GLY N	-2.522	39.082	-0.681
127	GLY CA	-3.835	37.871	0.193	127	GLY C	-3.176	38.180	1.682
127	GLY O	-2.446	38.030	2.220	128	GLY N	-4.121	37.443	2.222
128	GLY CA	-4.675	37.496	3.642	128	GLY C	-4.644	36.038	4.164
128	GLY O	-4.983	35.158	3.276	129	PRO N	-4.919	35.857	5.482
129	PRO CA	-4.671	34.329	5.998	129	PRO C	-6.116	34.886	6.082
129	PRO O	-8.338	32.887	6.305	129	PRO CB	-4.060	34.684	7.384
129	PRO CG	-6.619	36.116	7.727	130	SER CA	-4.239	36.870	6.418
130	SER N	-7.051	35.015	5.912	130	SER O	-8.670	34.611	6.023
130	SER C	-9.218	34.884	4.726	131	GLY N	-8.949	35.881	4.026
130	SER CB	-9.069	35.351	7.216	131	GLY C	-8.723	34.626	8.403
131	GLY N	-10.083	33.967	4.349	132	SER N	-10.824	34.229	3.974
131	GLY C	-12.205	34.713	3.562	132	SER CA	-12.495	34.722	4.781
132	SER N	-13.040	35.038	2.594	132	SER O	-14.607	33.433	3.011
132	SER C	-15.289	34.805	1.936	133	ALA CA	-14.799	34.986	6.824
132	SER CB	-14.990	36.927	3.145	133	ALA O	-16.693	37.539	1.875
133	ALA N	-16.847	34.588	2.294	134	ALA N	-17.907	34.857	1.324
133	ALA C	-17.650	34.965	0.087	134	ALA C	-17.743	34.427	-1.814
133	ALA CB	-18.866	33.828	1.996	134	ALA CB	-17.883	36.268	0.294
134	ALA CA	-16.872	37.259	-0.702	135	LEU CA	-16.635	37.369	-1.674
134	ALA O	-16.781	37.585	-2.869	135	LEU O	-18.263	38.600	-0.187
135	LEU N	-15.478	37.229	-1.046	135	LEU CB	-14.197	37.244	-1.804
135	LEU CA	-14.158	36.005	-2.705	135	LEU CG	-13.794	36.020	-3.890
135	LEU O	-13.038	37.328	-0.798	135	LEU CD2	-11.693	37.190	-1.588
135	LEU CB	-11.460	36.615	-2.292	136	LYS CA	-10.582	36.807	-0.819
135	LEU CD1	-14.809	36.823	-2.173	136	LYS C	-14.563	33.997	-3.813
136	LYS N	-15.544	33.739	-4.190	136	LYS CG	-15.279	33.431	-5.205
136	LYS C	-16.903	32.341	-2.136	136	LYS CE	-14.743	31.967	-3.843
136	LYS CB	-15.883	29.892	-2.134	137	ALA N	-16.746	28.707	-2.778
136	LYS CD	-15.308	28.411	-4.140	137	ALA C	-17.338	34.260	-3.847
136	LYS NZ	-17.795	34.416	-4.893	137	ALA CB	-19.094	35.383	-6.045
137	ALA CA	-17.708	35.049	-7.208	138	ALA CA	-18.001	34.941	-4.263
138	ALA N	-16.529	36.301	-5.729	138	ALA O	-16.985	37.311	-6.685
138	ALA C	-14.903	36.696	-7.557	139	VAL N	-15.950	36.843	-8.762
138	ALA CB	-15.522	38.867	-5.934	139	VAL C	-13.623	35.959	-7.827
139	VAL CA	-12.946	39.291	-7.837	139	VAL CB	-11.830	34.226	-8.720
139	VAL O	-13.208	34.070	-9.877	139	VAL CG2	-11.878	34.671	-6.968
139	VAL CG1	-10.919	33.856	-7.866	140	ASP CA	-13.274	33.780	-6.233
140	ASP N	-16.993	33.936	-8.122	140	ASP O	-16.080	32.498	-8.929
140	ASP C	-16.823	33.131	-10.084	141	ASP CG	-15.388	32.579	-11.180
140	ASP CB	-16.169	31.849	-8.188	140	ASP OD2	-16.139	30.648	-7.186
140	ASP OD1	-14.178	30.408	-7.282	141	LYS CA	-17.373	30.182	-6.329
141	LYS N	-16.658	34.263	-9.820	141	LYS O	-16.780	35.086	-10.868
141	LYS C	-18.373	35.419	-11.966	141	LYS CG	-18.884	35.248	-13.113
141	LYS CB	-18.039	36.278	-10.325	141	LYS CE	-20.572	37.036	-11.306
141	LYS CD	-19.586	36.187	-10.536	142	ALA N	-19.167	39.051	-11.250
141	LYS NZ	-21.198	40.037	-10.275	142	ALA C	-13.818	35.868	-11.866
142	ALA CA	-16.173	36.192	-12.614	142	ALA CB	-12.870	35.010	-13.021
142	ALA O	-18.778	35.169	-16.795	143	VAL CA	-13.168	36.697	-11.948
143	VAL N	-15.882	33.886	-12.832	143	VAL O	-16.140	32.795	-13.650
143	VAL C	-16.348	32.233	-14.496	143	VAL CG1	-12.300	31.886	-15.639
143	VAL CB	-12.881	31.673	-12.716	144	ALA N	-15.531	30.370	-13.661
143	VAL CG2	-11.385	32.195	-12.014	144	ALA C	-16.920	32.288	-13.878
144	ALA CA	-16.764	31.836	-14.641				32.681	-15.841

144	ALA	C	-17.388	32.263	-14.958	144	ALA	CB	-17.942	31.968	-13.788
145	SER	N	-16.307	33.968	-13.704	145	SER	CA	-16.682	34.917	-14.786
145	SER	C	-15.609	34.773	-17.829	145	SER	O	-15.910	35.321	-18.893
145	SER	CB	-17.016	36.376	-16.414	145	SER	OG	-19.882	36.935	-18.849
146	GLY	N	-14.877	33.986	-17.565	146	GLY	CA	-13.619	33.799	-18.871
146	GLY	C	-12.273	34.491	-18.385	146	GLY	O	-11.428	34.386	-19.266
147	VAL	N	-12.158	35.162	-17.284	147	VAL	CA	-10.874	35.856	-16.912
147	VAL	C	-9.858	34.836	-16.323	147	VAL	O	-10.171	33.991	-15.486
147	VAL	CB	-11.152	36.977	-15.889	147	VAL	CG1	-9.896	37.803	-15.878
147	VAL	CG2	-12.340	37.918	-16.230	148	VAL	N	-8.583	35.018	-16.693
148	VAL	CA	-7.482	34.230	-16.808	148	VAL	C	-7.157	34.907	-16.781
148	VAL	O	-6.840	36.133	-16.750	148	VAL	CB	-6.273	34.126	-16.958
148	VAL	CG1	-5.879	33.483	-16.281	148	VAL	CG2	-6.890	33.432	-18.262
149	VAL	N	-7.258	34.355	-13.531	149	VAL	CA	-6.987	34.965	-12.249
149	VAL	C	-5.788	34.385	-11.613	149	VAL	O	-5.624	33.173	-11.439
149	VAL	CB	-8.224	34.890	-11.315	149	VAL	CG1	-7.893	35.619	-10.989
149	VAL	CG2	-9.486	35.386	-12.096	150	VAL	N	-4.732	35.301	-11.404
150	VAL	CA	-3.393	34.987	-10.901	150	VAL	C	-3.157	35.625	-9.559
150	VAL	O	-3.592	36.778	-9.480	150	VAL	CB	-2.274	35.389	-11.951
150	VAL	CG1	-0.973	34.633	-11.461	150	VAL	CG2	-2.678	34.043	-13.381
151	ALA	N	-2.868	36.946	-8.595	151	ALA	CA	-2.361	35.882	-7.287
151	ALA	C	-1.080	35.036	-6.637	151	ALA	O	-0.418	33.889	-6.984
151	ALA	CB	-3.557	33.390	-6.307	152	ALA	N	-0.490	35.987	-8.822
152	ALA	CA	0.714	35.438	-5.112	152	ALA	C	0.384	36.328	-6.158
152	ALA	O	-0.728	36.466	-3.467	152	ALA	CB	1.266	36.607	-4.294
153	ALA	N	1.125	33.302	-5.912	153	ALA	CA	0.848	32.258	-2.963
153	ALA	C	0.931	32.725	-1.911	153	ALA	O	0.317	32.192	-0.599
153	ALA	CB	1.750	31.838	-3.195	154	GLY	N	1.827	33.693	-1.244
154	GLY	CA	2.843	34.211	0.125	154	GLY	C	3.319	36.069	0.388
154	GLY	O	4.189	33.267	-0.118	155	ASN	N	3.958	34.781	1.568
155	ASN	CA	5.344	34.787	2.037	155	ASN	C	5.199	34.258	3.462
155	ASN	O	6.181	34.829	4.295	155	ASN	CB	6.008	36.198	1.904
155	ASN	CG	5.890	36.702	0.500	155	ASN	OD1	6.123	36.865	-0.534
155	ASN	ND2	5.494	37.965	0.352	156	GLU	N	4.711	33.168	3.675
156	GLU	CA	4.633	32.537	4.970	156	GLU	C	3.322	31.928	5.183
156	GLU	O	3.376	30.637	6.222	156	GLU	CB	3.285	31.980	3.188
156	GLU	CG	2.491	32.442	6.368	156	GLU	CD	2.394	33.931	6.270
156	GLU	OE1	1.744	34.322	5.312	156	GLU	OE2	3.106	34.436	7.146
157	GLY	N	0.389	31.057	4.227	157	GLY	CA	7.386	29.917	4.387
157	GLY	C	4.803	28.622	4.553	157	GLY	O	5.416	28.346	4.889
158	THR	N	7.147	27.793	5.382	158	THR	CG2	8.079	25.396	3.859
158	THR	OG1	8.707	25.487	6.217	158	THR	CB	7.864	25.346	5.296
158	THR	CA	6.952	26.487	5.702	158	THR	C	6.188	26.480	7.157
158	THR	O	6.479	27.335	7.077	159	SER	N	5.338	25.441	7.497
159	SER	OG	3.141	25.906	10.525	159	SER	CB	3.673	26.185	9.212
159	SER	CA	4.833	25.210	8.956	159	SER	C	4.494	25.720	8.946
159	SER	O	3.339	23.281	9.030	160	GLY	N	5.574	22.967	8.935
160	GLY	CA	5.434	21.504	8.995	160	GLY	C	4.576	21.049	7.738
160	GLY	O	4.808	21.326	6.555	161	SER	N	3.925	20.310	8.116
161	SER	CA	2.686	19.777	7.054	161	SER	C	1.477	20.706	6.786
161	SER	O	3.696	20.347	5.869	161	SER	CB	2.344	18.293	7.271
161	SER	OG	1.854	18.028	8.595	162	SER	N	1.383	22.341	7.459
162	SER	CA	0.167	22.725	7.113	162	SER	C	0.430	23.552	5.848
162	SER	O	1.333	23.840	9.994	162	SER	CB	-0.213	23.666	8.262
162	SER	OG	0.184	23.091	9.480	163	SER	N	-0.679	23.921	8.197
163	SER	CA	-0.611	24.750	3.998	163	SER	C	-0.441	26.177	4.513
163	SER	O	-1.878	26.868	5.804	163	SER	CB	-1.890	24.642	3.211
163	SER	OG	-1.992	25.718	2.331	164	THR	N	0.387	26.952	3.852
164	THR	CA	0.609	28.260	4.312	164	THR	C	0.188	29.286	3.194
164	THR	O	0.485	30.582	3.278	164	THR	CB	2.095	28.518	4.818
164	THR	OG1	2.984	26.282	3.692	164	THR	CG2	2.397	27.610	6.001
165	VAL	N	-0.513	28.742	2.198	165	VAL	CA	-0.959	29.542	1.018
165	VAL	C	-2.828	30.548	1.497	165	VAL	O	-2.929	30.192	2.280

165	VAL CB	-1.339	28.624	-8.161
165	VAL CG2	-3.210	27.716	-8.895
166	GLY CA	-2.943	32.778	1.826
166	GLY O	-4.124	32.394	-8.396
167	TYR CA	-6.223	34.066	8.113
167	TYR O	-5.474	36.283	8.084
167	TYR CG	-7.791	32.984	1.789
167	TYR CD2	-8.710	32.116	1.193
167	TYR CE2	-9.868	30.955	1.809
167	TYR OH	-8.882	29.481	2.658
168	PRO CG	-6.943	34.376	-3.928
168	PRO CB	-7.964	35.344	-3.905
168	PRO C	-6.398	33.334	-3.270
169	GLY N	-5.886	33.193	-3.189
169	GLY C	-4.937	30.702	-3.470
170	LYS N	-5.602	30.579	-2.289
170	LYS C	-7.055	28.773	-2.316
170	LYS CB	-6.266	29.294	-8.216
170	LYS CD	-6.250	28.289	2.031
170	LYS NZ	-4.259	27.463	3.215
171	TYR CA	-9.812	29.843	-3.859
171	TYR O	-7.760	28.714	-5.928
171	TYR CG	-10.497	30.984	-3.047
171	TYR CD2	-10.456	32.374	-3.026
171	TYR CE2	-10.961	33.088	-1.936
171	TYR OH	-12.806	33.319	8.170
172	PRO CA	-9.093	26.417	-6.596
172	PRO O	-8.325	26.784	-9.881
172	PRO CG	-10.630	25.271	-9.096
173	SER N	-10.897	26.167	-8.019
173	SER C	-9.015	29.773	-9.595
173	SER CB	-11.528	29.623	-9.481
174	VAL N	-8.162	29.944	-8.614
174	VAL C	-5.784	30.131	-9.068
174	VAL CB	-6.899	31.775	-7.896
174	VAL CG2	-8.220	32.503	-7.323
175	ILE CA	-3.869	30.186	-10.024
175	ILE O	-2.450	31.958	-8.955
175	ILE CG1	-3.857	29.978	-12.924
175	ILE CD1	-3.692	30.529	-13.946
176	ALA CA	-1.335	30.517	-6.870
176	ALA O	8.453	29.218	-7.838
177	VAL N	8.864	31.410	-7.180
177	VAL C	3.225	31.693	-6.473
177	VAL CB	2.439	33.607	-8.755
177	VAL CG2	1.374	32.552	-9.845
178	GLY CA	5.168	30.703	-5.339
178	GLY O	6.499	31.435	-7.286
179	ALA CA	8.715	32.037	-5.859
179	ALA O	10.198	30.681	-4.719
180	VAL N	10.659	31.162	-6.885
180	VAL C	13.048	31.585	-7.171
180	VAL CB	12.878	29.514	-8.166
180	VAL CG2	11.675	30.129	-9.000
181	ASP CA	15.431	32.108	-7.039
181	ASP O	15.339	31.090	-9.292
181	ASP CG	17.128	30.534	-5.971
181	ASP OD2	17.680	30.256	-4.887
182	SER CA	17.622	32.214	-10.191
182	SER O	18.365	30.452	-11.678
182	SER OG	18.816	34.361	-10.475
183	SER CA	18.716	28.665	-9.444
183	SER O	17.859	26.413	-9.897
165	VAL CG1	-1.947	29.357	-1.874
166	GLY N	-1.910	31.821	1.129
166	GLY C	-4.898	32.859	8.817
167	TYR N	-5.884	33.738	8.979
167	TYR C	-5.993	35.289	-8.696
167	TYR CB	-7.644	34.252	8.964
167	TYR CD1	-7.288	32.783	2.947
167	TYR CE1	-7.567	31.528	3.618
167	TYR CZ	-8.686	30.671	3.846
168	PRO N	-6.380	33.499	-1.850
168	PRO CD	-6.273	34.752	-2.624
168	PRO CA	-7.134	34.457	-2.868
168	PRO O	-7.897	32.528	-3.912
169	GLY CA	-4.446	32.877	-3.927
169	GLY O	-4.880	29.733	-4.249
170	LYS CA	-5.856	29.268	-1.748
170	LYS O	-7.308	27.884	-2.524
170	LYS CG	-5.795	28.186	8.883
170	LYS CE	-5.731	27.271	3.829
171	TYR N	-7.838	29.616	-3.148
171	TYR C	-8.483	28.309	-5.113
171	TYR CB	-9.962	30.224	-4.242
171	TYR CD1	-11.860	30.305	-1.982
171	TYR CE1	-11.520	31.883	-8.867
171	TYR CZ	-11.528	32.398	-8.886
172	PRO N	-9.297	27.204	-5.376
172	PRO C	-9.233	27.156	-7.909
172	PRO CB	-10.167	29.329	-6.513
172	PRO CD	-10.364	26.469	-4.514
173	SER CA	-10.220	25.818	-9.338
173	SER O	-8.968	30.233	-10.742
173	SER OG	-11.595	30.566	-8.406
174	VAL CA	-7.853	30.691	-8.855
174	VAL O	-5.612	29.152	-8.344
174	VAL CG1	-5.796	32.837	-7.617
175	ILE N	-6.911	30.729	-9.885
175	ILE C	-2.714	30.736	-8.894
175	ILE CB	-2.953	30.524	-11.419
175	ILE CG2	-1.451	30.089	-11.512
176	ALA N	-2.220	30.028	-7.925
176	ALA C	8.120	30.381	-7.310
176	ALA CB	-1.639	29.838	-5.841
177	VAL CA	2.261	31.836	-7.656
177	VAL O	3.178	32.697	-5.721
177	VAL CG1	3.842	32.667	-9.392
178	GLY N	4.877	30.694	-6.398
178	GLY C	6.446	31.233	-6.874
179	ALA N	7.812	31.447	-5.287
179	ALA C	9.939	31.899	-6.779
179	ALA CB	9.025	33.251	-4.973
180	VAL CA	11.970	30.482	-6.981
180	VAL O	12.712	32.691	-7.627
180	VAL CG1	11.271	28.251	-7.833
181	ASP N	14.267	31.203	-6.980
181	ASP C	15.942	31.804	-8.662
181	ASP CB	16.466	31.921	-8.914
181	ASP OD1	17.193	29.785	-6.972
182	SER N	17.087	32.286	-8.847
182	SER C	20.193	30.817	-10.496
182	SER CB	18.678	33.313	-10.464
183	SER N	18.258	30.042	-9.423
183	SER C	17.881	27.616	-9.947
183	SER CB	19.256	28.223	-8.987

183	SER	OG	20.589	28.615	-8.281	194	ASN	N	16.373	28.894	-9.882
184	ASN	CA	15.164	27.317	-9.880	194	ASN	C	16.931	26.728	-8.197
184	ASN	O	14.135	23.759	-8.897	194	ASN	CB	18.016	26.941	-10.722
184	ASN	CG	14.993	26.998	-12.076	194	ASN	OD1	16.788	28.184	-12.277
184	ASN	ND2	15.852	26.218	-13.076	195	GLN	N	15.942	27.247	-7.159
185	GLN	CA	15.278	26.846	-5.935	195	GLN	C	14.280	27.494	-5.283
185	GLN	O	14.159	28.726	-5.384	195	GLN	CB	16.599	26.568	-5.181
185	GLN	CG	16.539	26.242	-3.614	195	GLN	CD	18.011	26.182	-3.284
185	GLN	OE1	16.864	25.799	-4.861	195	GLN	NE2	18.266	26.384	-1.934
186	ARG	N	13.278	26.950	-6.668	196	ARG	CA	12.185	27.774	-3.841
186	ARG	C	12.788	28.782	-2.866	196	ARG	O	13.698	28.384	-2.893
186	ARG	CB	11.315	26.843	-3.116	196	ARG	CG	10.214	27.471	-2.161
186	ARG	CD	9.447	26.337	-1.668	196	ARG	NE	9.066	26.333	-0.117
186	ARG	CZ	9.961	26.879	1.059	196	ARG	NH2	9.367	27.888	1.658
186	ARG	NH2	10.966	26.921	1.783	197	ALA	N	12.294	30.689	-2.893
187	ALA	CA	12.728	31.864	-1.895	197	ALA	C	12.262	28.604	-0.817
187	ALA	O	11.158	30.843	-0.387	197	ALA	CB	13.144	32.402	-2.344
188	SER	N	13.851	30.770	0.849	198	SER	CA	12.671	28.286	1.868
188	SER	C	11.336	30.847	2.412	198	SER	O	13.740	30.111	3.212
188	SER	CB	13.747	30.456	2.932	198	SER	OG	14.137	31.826	2.841
189	PHE	N	10.963	32.010	1.974	199	PHE	CA	9.697	32.688	2.418
189	PHE	C	8.499	32.198	3.609	199	PHE	O	9.389	32.556	2.811
189	PHE	CB	9.787	34.217	2.243	199	PHE	CG	10.117	34.696	0.867
189	PHE	CD1	9.147	34.830	-0.121	199	PHE	CD2	11.418	35.116	0.567
189	PHE	CE1	9.483	35.187	-1.411	199	PHE	CE2	11.769	35.945	-0.781
189	PHE	CZ	10.786	35.886	-1.725	200	SER	N	8.703	31.826	0.499
190	SER	CA	7.626	31.094	-0.391	200	SER	C	6.863	30.162	0.328
190	SER	O	7.834	29.883	0.866	200	SER	CB	8.181	30.598	-1.788
190	SER	OG	7.136	28.337	-2.618	201	SER	N	5.388	29.951	0.326
191	SER	CA	4.361	29.478	0.987	201	SER	C	4.261	28.330	0.223
191	SER	O	4.543	28.268	-0.895	201	SER	CB	3.815	30.411	0.911
191	SER	OG	2.729	31.285	1.954	202	VAL	N	3.786	27.318	0.928
192	VAL	CA	3.629	25.932	0.391	202	VAL	C	2.284	25.291	0.686
192	VAL	O	3.599	25.498	1.598	202	VAL	CB	4.781	25.127	1.888
192	VAL	CG1	4.144	25.727	0.722	202	VAL	CG2	4.617	25.194	2.892
193	GLY	N	1.938	24.172	0.047	203	GLY	CA	0.629	23.564	0.416
193	GLY	C	0.081	23.029	-0.901	203	GLY	O	0.530	23.244	-2.015
194	PRO	N	-1.023	22.289	-0.722	204	PRO	CA	-1.662	21.451	-1.073
194	PRO	C	-2.237	22.605	-2.914	204	PRO	O	-2.403	22.244	-4.085
194	PRO	CB	-2.769	20.783	-1.210	204	PRO	CG	-2.311	20.622	0.213
194	PRO	CD	-1.633	21.954	0.578	205	GLU	N	-2.822	23.793	-2.439
195	GLU	CA	-3.145	24.850	-3.252	205	GLU	C	-2.095	25.631	-4.858
195	GLU	O	-2.816	26.398	-4.936	205	GLU	CB	-4.043	26.786	-2.478
195	GLU	CG	-4.942	25.134	-1.635	205	GLU	CD	-4.315	24.860	-0.180
195	GLU	OE1	-3.110	24.960	0.165	205	GLU	OE2	-5.138	24.520	0.783
196	LEU	N	-0.829	23.264	-3.870	206	LEU	CA	0.261	25.929	-4.664
196	LEU	C	0.228	23.376	-6.059	206	LEU	O	0.305	26.121	-6.153
196	LEU	CB	1.568	25.739	-3.854	206	LEU	CG	2.770	26.178	-4.643
196	LEU	CD1	2.739	27.716	-4.639	206	LEU	CD2	4.027	25.721	-3.911
197	ASP	N	0.140	26.208	-7.093	207	ASP	CA	0.832	25.774	-8.480
197	ASP	C	1.307	25.738	-9.293	207	ASP	O	1.853	24.734	-9.916
197	ASP	CB	-1.067	26.592	-9.191	207	ASP	CG	-2.406	26.351	-8.549
197	ASP	OD1	-2.804	25.155	-8.334	207	ASP	OD2	-3.035	27.327	-8.888
198	VAL	N	2.013	26.889	-9.344	208	VAL	CA	3.206	26.970	-10.209
198	VAL	C	4.157	27.950	-9.514	208	VAL	O	3.752	28.699	-8.587
198	VAL	CB	2.894	27.476	-11.637	208	VAL	CG1	1.938	26.726	-12.537
198	VAL	CG2	2.337	28.919	-11.484	209	MET	N	5.274	27.916	-10.016
199	MET	CA	6.430	28.802	-9.498	209	MET	C	6.845	29.810	-10.578
199	MET	O	6.696	29.518	-11.793	209	MET	CB	7.668	27.978	-9.077
199	MET	CG	7.365	26.849	-8.139	209	MET	SD	6.755	27.449	-6.568
199	MET	CE	8.227	27.785	-8.587	210	ALA	N	7.426	30.962	-10.181
200	ALA	CA	7.991	31.929	-11.055	210	ALA	C	8.868	32.666	-10.272
200	ALA	O	8.127	32.824	-9.860	210	ALA	CB	6.932	32.878	-11.638

201	PRO N	9.927	33.495	-18.951
201	PRO C	10.490	35.127	-9.238
201	PRO CB	11.817	34.723	-11.490
201	PRO CD	8.941	33.616	-12.408
202	GLY CA	10.473	36.234	-7.844
202	GLY O	11.332	37.124	-4.979
203	VAL CA	13.948	36.929	-5.716
203	VAL C	15.133	37.731	-7.593
203	VAL CG1	16.098	36.106	-6.612
204	SER N	16.869	39.182	-5.859
204	SER C	18.067	40.619	-7.872
204	SER CB	17.087	39.976	-6.326
205	ILE N	19.771	40.869	-8.008
205	ILE C	19.207	42.769	-9.478
205	ILE CB	21.532	40.833	-9.144
205	ILE CG2	20.899	41.281	-10.467
206	GLN N	23.956	43.095	-10.489
206	GLN C	23.002	44.978	-11.630
206	GLN CB	25.455	44.708	-11.740
206	GLN CD	27.285	45.165	-10.807
206	GLN NE2	26.556	46.260	-9.857
207	SER CA	21.217	46.571	-11.987
207	SER O	21.919	48.657	-11.084
207	SER OG	8.993	46.856	-12.613
208	THR CG2	9.171	50.339	-14.784
208	THR CB	8.620	50.415	-13.397
208	THR C	9.197	50.488	-10.803
209	LEU N	9.656	51.613	-10.228
209	LEU C	8.673	53.610	-9.262
209	LEU CB	10.335	52.192	-7.988
209	LEU CD1	11.968	51.114	-8.472
210	PRO N	7.700	54.139	-8.444
210	PRO C	8.383	56.573	-8.639
210	PRO CB	6.302	55.733	-7.917
210	PRO CD	7.193	53.491	-7.271
211	GLY CA	9.069	58.765	-9.610
211	GLY O	11.176	59.005	-10.259
212	ASN CA	10.903	57.422	-12.643
212	ASN O	13.188	57.181	-12.420
212	ASN CG	11.803	58.185	-14.814
212	ASN ND2	12.273	59.159	-15.576
213	LYS CA	12.810	54.946	-10.537
213	LYS O	11.775	53.039	-11.613
213	LYS CG	13.206	54.694	-8.767
213	LYS CE	14.195	55.218	-6.870
214	TYR N	13.681	52.703	-10.444
214	TYR C	14.383	50.680	-9.489
214	TYR CB	16.641	50.981	-11.984
214	TYR CD1	16.689	52.847	-13.678
214	TYR CE1	16.230	53.475	-14.814
214	TYR CZ	13.204	52.895	-15.850
215	GLY N	14.858	48.947	-9.158
215	GLY C	14.196	47.325	-7.749
216	ALA N	14.810	46.638	-8.831
216	ALA C	13.692	44.922	-5.912
216	ALA CB	15.715	44.954	-6.887
217	TYR CA	11.964	43.488	-4.640
217	TYR O	12.202	41.642	-3.696
217	TYR CG	10.117	43.291	-4.214
217	TYR CD2	9.016	43.933	-4.785
217	TYR CE2	8.654	47.219	-4.381
217	TYR OH	8.953	49.160	-2.988
218	ASN CA	11.640	39.042	-3.227
201	PRO CA	11.818	34.138	-10.238
201	PRO B	9.579	35.987	-9.682
201	PRO CG	11.392	34.848	-12.678
202	GLY N	10.929	35.206	-8.821
202	GLY C	11.588	36.498	-6.115
203	VAL N	12.815	36.583	-6.613
203	VAL C	14.786	38.017	-6.469
203	VAL CB	14.814	35.688	-5.381
203	VAL CG2	14.879	34.741	-4.178
204	SER CA	15.572	40.281	-4.487
204	SER C	15.786	40.685	-8.889
204	SER OG	17.732	41.186	-6.472
205	ILE CA	13.869	41.234	-9.228
205	ILE B	12.675	43.498	-8.648
205	ILE CG1	11.436	39.396	-8.810
205	ILE CD1	12.257	38.412	-9.771
206	GLN CA	16.204	44.917	-10.834
206	GLN B	12.669	44.218	-12.621
206	GLN CG	16.884	44.163	-10.980
206	GLN OE1	18.328	44.936	-9.383
207	SER N	12.359	46.864	-11.214
207	SER C	11.899	48.093	-11.749
207	SER CB	9.918	49.053	-11.569
208	THR N	10.854	48.664	-12.326
208	THR OG1	7.570	49.414	-13.144
208	THR CA	9.675	50.092	-12.175
208	THR B	8.423	49.887	-10.049
209	LEU CA	9.192	52.158	-8.959
209	LEU B	9.160	54.227	-10.222
209	LEU CG	10.804	55.816	-7.416
209	LEU CD2	9.607	56.282	-8.649
210	PRO CA	7.273	55.817	-8.649
210	PRO B	9.491	56.445	-8.104
210	PRO CG	8.884	56.379	-6.964
211	GLY N	8.077	57.665	-9.355
211	GLY C	10.894	58.454	-10.498
212	ASN N	9.851	57.770	-11.587
212	ASN C	12.089	56.783	-12.856
212	ASN CB	11.224	58.998	-13.499
212	ASN OD1	11.853	57.854	-15.323
213	LYS N	11.803	55.749	-11.247
213	LYS C	12.668	53.499	-10.866
213	LYS CB	12.769	55.241	-9.859
213	LYS CD	13.246	57.030	-7.312
213	LYS NZ	15.048	56.705	-7.921
214	TYR CA	13.889	51.246	-10.722
214	TYR B	19.211	51.253	-8.817
214	TYR CG	24.130	51.621	-13.246
214	TYR CD2	23.129	51.065	-14.814
214	TYR CE2	22.654	51.669	-15.178
214	TYR OH	22.756	53.458	-16.696
215	GLY CA	14.622	48.772	-7.905
215	GLY B	13.249	46.917	-8.321
216	ALA CA	14.454	45.208	-6.781
216	ALA B	13.948	43.527	-6.678
217	TYR N	12.758	43.982	-8.979
217	TYR C	12.033	41.928	-6.547
217	TYR CZ	18.673	43.862	-6.570
217	TYR CD1	18.846	45.991	-3.836
217	TYR CE1	18.459	47.267	-2.790
217	TYR CZ	9.388	47.882	-3.391
218	ASN N	11.798	41.386	-3.391
218	ASN C	10.284	39.636	-2.749

218	ASN B	9.763	43.347	-1.917
218	ASN CG	10.831	39.966	-2.341
218	ASN ND2	10.660	39.644	-1.165
219	GLY CA	9.382	38.132	-2.649
219	GLY C	7.873	37.902	-4.876
220	THR N	5.697	35.936	-4.179
220	THR CA	4.417	36.742	-5.038
220	THR B	4.136	35.563	-2.491
220	THR OG1	4.738	38.238	-4.303
221	SER N	4.760	39.641	-4.381
221	SER C	3.323	40.383	-4.946
221	SER CB	6.063	39.389	-6.485
222	MET N	2.768	41.333	-4.993
222	MET SD	0.351	40.018	-7.218
222	MET CE	4.877	38.435	-8.367
222	MET C	4.554	37.246	-8.041
223	ALA N	5.200	36.068	-9.707
223	ALA C	6.509	34.807	-9.923
223	ALA CB	2.758	36.488	-9.709
224	SER CA	2.165	36.193	-12.057
224	SER B	0.692	36.895	-9.197
224	SER OG	2.895	39.130	-12.639
225	PRO CA	3.606	38.650	-14.804
225	PRO B	4.411	40.402	-10.764
225	PRO CG	4.769	37.626	-13.299
226	HIS N	4.618	35.947	-15.061
226	HIS C	6.008	36.048	-13.765
226	HIS CB	5.048	37.488	-12.170
226	HIS ND1	9.278	38.952	-12.236
226	HIS CE1	8.593	38.366	-14.199
227	VAL N	1.479	35.197	-15.621
227	VAL C	2.103	33.444	-13.619
227	VAL CB	3.294	32.665	-12.891
227	VAL CG2	0.011	37.109	-15.917
228	ALA CA	-0.253	37.435	-17.828
228	ALA B	1.791	38.028	-16.961
229	GLY N	2.428	37.197	-19.187
229	GLY C	2.711	35.988	-18.666
230	ALA N	1.424	34.500	-20.153
230	ALA C	3.298	33.624	-18.709
230	ALA CB	-1.010	34.416	-19.764
231	ALA CA	-1.909	33.896	-21.952
231	ALA B	-0.778	36.657	-21.721
232	ALA N	-0.281	37.284	-23.078
232	ALA C	-0.742	39.121	-21.377
232	ALA CB	1.617	36.293	-24.209
233	LEU CA	0.696	35.231	-26.111
233	LEU B	3.996	36.994	-23.453
233	LEU CG	4.241	37.893	-24.680
233	LEU CD2	6.306	38.684	-21.657
233	ILE CD1	-0.811	32.814	-23.570
234	ILE CB	-0.606	33.076	-24.644
234	ILE CA	-1.883	33.164	-26.546
234	ILE B	-3.596	35.028	-25.423
235	LEU CA	-4.109	35.814	-27.589
235	LEU B	-5.149	34.899	-23.362
235	LEU CG	-6.252	34.138	-24.120
235	LEU CD2	-1.764	37.237	-27.986
236	SER CA	-1.748	36.636	-30.290
236	SER B	0.599	37.971	-27.582
236	SER OG	-0.846	34.085	-29.952
237	LYS CA	-2.378	32.981	-31.644
237	LYS B	0.677	33.240	-30.716
237	LYS CG			

218	ASN CB	12.953	39.360	-2.134
218	ASN OD1	14.612	39.709	-3.622
219	GLY N	9.678	38.934	-2.289
219	GLY C	7.878	37.384	-3.681
220	THR N	6.561	36.638	-3.288
220	THR C	4.879	37.044	-4.864
220	THR CB	4.825	34.819	-3.926
220	THR CG2	3.784	33.696	-2.980
221	SER CA	3.984	39.201	-5.169
221	SER B	4.117	40.288	-7.277
221	SER OG	3.435	40.282	-3.149
222	MET CE	0.471	42.771	-3.173
222	MET CG	3.504	41.399	-8.602
222	MET CA	6.916	39.670	-7.638
222	MET B	7.884	38.867	-9.775
223	ALA CA	6.469	36.020	-8.885
223	ALA B	5.133	35.968	-10.929
224	SER N	4.074	36.360	-9.838
224	SER C	2.661	37.161	-11.839
224	SER CB	1.801	36.995	-8.603
225	PRO N	3.156	38.411	-11.159
225	PRO C	3.764	38.469	-13.626
225	PRO CB	5.653	40.511	-12.894
225	PRO CD	3.735	39.224	-10.894
226	HIS CA	5.446	36.879	-14.862
226	HIS B	4.625	35.809	-16.293
226	HIS CG	7.814	36.859	-13.358
226	HIS CD2	8.883	37.118	-14.167
226	HIS NE2	9.771	37.864	-13.663
227	VAL CA	2.883	34.388	-14.727
227	VAL B	1.018	34.773	-16.690
227	VAL CG1	1.076	32.676	-14.246
228	ALA N	1.003	36.242	-14.814
228	ALA C	0.943	37.538	-16.988
228	ALA CB	-0.307	38.353	-14.668
229	GLY CA	2.352	38.408	-18.239
229	GLY B	2.189	37.375	-20.384
230	ALA CA	2.794	34.801	-19.946
230	ALA B	1.380	34.208	-21.343
231	ALA N	0.385	34.823	-19.328
231	ALA C	-1.256	33.428	-20.864
231	ALA CB	-1.932	34.664	-18.849
232	ALA CA	-1.013	37.663	-21.782
232	ALA B	-0.861	37.901	-24.187
233	LEU N	0.935	38.726	-22.967
233	LEU C	0.821	39.169	-24.880
233	LEU CB	3.063	38.877	-23.907
233	LEU CD1	5.259	36.342	-22.921
234	ILE N	0.357	36.199	-24.047
234	ILE CG1	0.494	31.223	-23.109
234	ILE CG2	-1.803	30.900	-24.891
234	ILE C	-1.621	33.997	-25.436
235	LEU N	-2.390	36.665	-24.779
235	LEU C	-3.258	39.843	-26.672
235	LEU CB	-4.432	35.765	-24.378
235	LEU CD1	-5.652	35.683	-22.145
236	SER N	-2.896	36.438	-26.798
236	SER C	-1.491	36.292	-29.144
236	SER CB	-0.633	38.234	-27.733
237	LYS N	-1.066	35.067	-28.882
237	LYS C	-2.113	33.277	-30.268
237	LYS CB	0.272	33.112	-29.951
237	LYS CD	2.020	31.935	-30.662

237	LYS	CB	2.348	30.782	-31.729	237	LYS	NZ	8.828	29.848	-31.596
238	HIS	N	-2.951	31.999	-29.915	238	HIS	CA	-6.168	32.163	-29.279
238	HIS	C	-5.336	32.899	-28.697	238	HIS	O	-5.719	32.984	-27.562
238	HIS	CB	-3.948	30.862	-28.511	238	HIS	CG	-5.889	29.921	-29.237
238	HIS	ND1	-1.707	29.679	-28.835	238	HIS	CD2	-3.137	29.298	-30.394
238	HIS	CE1	-1.886	28.851	-29.642	238	HIS	NE2	-1.968	28.680	-30.399
239	PRO	N	-5.848	33.917	-28.552	239	PRO	CA	-6.988	34.779	-28.778
239	PRO	C	-8.284	34.552	-28.732	239	PRO	O	-8.969	34.819	-27.662
239	PRO	CB	-7.818	35.977	-29.713	239	PRO	CG	-6.666	35.294	-31.027
239	PRO	CD	-5.436	34.439	-30.688	240	ASN	N	-8.386	32.969	-29.227
240	ASN	CA	-9.829	32.041	-29.216	240	ASN	C	-9.908	31.180	-27.988
240	ASN	O	-10.949	30.618	-27.576	240	ASN	CB	-9.403	31.249	-30.535
240	ASN	CG	-7.971	30.827	-30.889	240	ASN	OD1	-7.898	31.598	-31.147
240	ASN	ND2	-7.670	29.888	-30.984	241	TRP	N	-8.384	31.806	-27.984
241	TRP	CA	-8.306	30.124	-26.120	241	TRP	C	-9.186	30.638	-26.936
241	TRP	O	-9.063	31.833	-24.686	241	TRP	CB	-8.879	29.830	-25.679
241	TRP	CG	-6.094	28.903	-26.857	241	TRP	CD1	-6.338	28.433	-27.818
241	TRP	CD2	-6.839	28.324	-26.185	241	TRP	NE1	-8.362	27.547	-28.231
241	TRP	CE2	-6.414	27.476	-27.216	241	TRP	CE3	-4.997	28.496	-24.981
241	TRP	CZ2	-3.195	26.786	-27.174	241	TRP	CZ3	-2.912	27.667	-24.943
241	TRP	CH2	-2.470	26.873	-26.009	242	THR	N	-9.737	29.781	-24.142
242	THR	CA	-10.458	30.119	-22.911	242	THR	C	-9.469	30.176	-21.747
242	THR	O	-8.335	29.674	-21.937	242	THR	CB	-11.570	29.032	-22.675
242	THR	OG1	-10.837	27.786	-22.476	242	THR	CG2	-12.494	28.987	-23.895
243	ASN	N	-8.966	30.659	-20.611	243	ASN	ND2	-11.787	30.686	-18.747
243	ASN	CA	-11.465	31.918	-18.788	243	ASN	CG	-11.093	31.191	-17.985
243	ASN	CB	-9.788	31.830	-18.332	243	ASN	O	-9.883	30.731	-19.644
243	ASN	C	-8.657	29.305	-19.010	244	THR	CA	-7.693	29.136	-18.448
244	THR	N	-9.964	28.362	-19.283	244	THR	O	-9.381	26.934	-19.859
244	THR	C	-8.133	26.393	-19.882	244	THR	OG1	-7.324	25.787	-19.111
244	THR	CB	-10.665	26.888	-19.494	245	GLN	N	-11.785	26.678	-18.684
244	THR	CG2	-10.553	24.595	-19.159	245	GLN	C	-8.082	26.716	-21.073
245	GLN	CA	-6.964	26.362	-21.962	245	GLN	CB	-8.647	27.820	-21.920
245	GLN	O	-4.873	26.393	-21.447	245	GLN	CD	-7.330	26.899	-23.397
245	GLN	CG	-8.285	25.526	-23.989	245	GLN	NE2	-8.493	25.873	-23.628
245	GLN	OE1	-9.306	26.769	-23.727	246	VAL	CA	-7.748	25.212	-24.378
246	VAL	N	-5.697	28.306	-21.218	246	VAL	O	-6.477	29.040	-20.778
246	VAL	C	-3.936	26.462	-19.467	246	VAL	CG1	-2.788	28.227	-19.361
246	VAL	CB	-4.779	30.555	-20.621	247	ARG	N	-3.544	31.272	-20.027
246	VAL	CG2	-5.169	31.138	-21.989	247	ARG	C	-4.767	28.240	-18.462
247	ARG	CA	-4.380	27.734	-17.168	247	ARG	CB	-3.770	26.292	-17.348
247	ARG	O	-2.705	25.985	-14.764	247	ARG	CD	-5.533	27.667	-16.149
247	ARG	CG	-4.987	27.095	-14.882	247	ARG	CZ	-6.894	27.179	-13.793
247	ARG	NE	-5.440	26.787	-12.946	247	ARG	NH2	-5.893	26.866	-11.815
247	ARG	NH1	-7.084	27.484	-11.210	248	SER	CA	-5.177	26.428	-10.270
248	SER	N	-4.480	25.908	-19.191	248	SER	O	-4.819	24.131	-18.626
248	SER	C	-2.657	24.986	-19.879	248	SER	OG	-6.166	23.253	-18.883
248	SER	CB	-5.894	23.408	-19.372	249	SER	CA	-1.223	23.890	-18.832
249	SER	N	-2.900	26.883	-20.136	249	SER	O	2.826	24.876	-20.891
249	SER	C	-0.071	25.302	-19.948	249	SER	OG	-3.388	24.788	-20.049
249	SER	CB	-1.369	25.756	-22.088	250	LEU	CD2	1.824	25.619	-22.956
250	LEU	N	-0.289	26.333	-19.169	250	LEU	CG	0.352	29.014	-18.222
250	LEU	CD1	-0.373	28.453	-17.268	250	LEU	CA	0.718	29.438	-18.151
250	LEU	CD	0.178	28.083	-17.905	250	LEU	O	2.283	26.837	-18.216
250	LEU	CB	1.092	29.694	-17.268	251	GLN	NE2	-2.750	28.421	-17.032
250	LEU	C	0.068	25.907	-16.714	251	GLN	CD	-2.949	29.512	-18.237
251	GLN	N	-2.819	23.424	-12.933	251	GLN	CB	-0.887	26.810	-13.834
251	GLN	OE1	-1.218	24.814	-13.994	251	GLN	C	0.989	28.621	-14.077
251	GLN	CG	0.881	23.941	-15.745	252	ASN	N	2.304	22.664	-16.361
251	GLN	CA	1.743	22.814	-15.616	252	ASN	C	2.804	22.394	-17.990
251	GLN	O	1.882	21.206	-18.282	252	ASN	CB	0.886	21.359	-18.991
252	ASN	CA	2.899	20.462	-19.768	252	ASN	OD1	-0.836	20.780	-19.292
252	ASN	O	-1.036	19.926	-18.873					19.395	-17.502
252	ASN	CG									

252	ASN HD2	-2.234	19.834	-19.561	
253	THR CA	4.234	22.717	-19.719	
253	THR O	4.948	23.733	-19.427	
253	THR OG1	3.993	24.937	-20.428	
254	THR N	5.218	23.177	-17.551	
254	THR C	7.466	22.730	-16.417	
254	THR CB	5.664	23.958	-15.132	
254	THR CG2	4.930	24.949	-14.802	
255	THR CA	8.771	22.594	-15.817	
255	THR O	9.439	22.786	-33.474	
255	THR OG1	11.882	23.709	-17.921	
256	LYS N	9.606	20.782	-34.314	
256	LYS C	10.522	20.333	-12.063	
256	LYS CB	9.024	18.998	-13.249	
256	LYS CD	10.284	16.948	-11.777	
256	LYS NZ	9.243	16.869	-11.854	
257	LEU CA	11.272	21.036	-9.893	
257	LEU O	12.096	20.865	-7.732	
257	LEU CG	11.357	23.620	-10.968	
257	LEU CD2	12.678	23.668	-11.325	
258	GLY CA	10.602	18.793	-6.879	
258	GLY O	8.283	18.956	-7.202	
259	ASP CA	9.787	17.896	-6.816	
259	ASP O	6.859	20.039	-6.214	
259	ASP CG	6.781	17.128	-2.241	
259	ASP OD2	7.098	16.299	-1.321	
260	SER CA	4.681	19.587	-5.529	
260	SER O	3.500	21.503	-6.446	
260	SER OG	2.765	17.937	-5.448	
261	PHE CA	3.831	20.468	-1.885	
261	PHE O	3.944	22.868	-1.432	
261	PHE CG	3.549	20.337	0.715	
261	PHE CD2	4.691	21.660	1.558	
261	PHE CE2	3.965	21.602	2.748	
262	TYR N	5.778	21.788	-2.305	
262	TYR C	6.820	23.689	-3.965	
262	TYR CB	8.123	22.493	-1.831	
262	TYR CD1	8.884	20.484	-0.364	
262	TYR CE1	8.862	19.873	0.882	
262	TYR CZ	8.069	20.672	2.018	
263	TYR N	6.626	23.104	-4.693	
263	TYR C	8.626	23.680	-6.956	
263	TYR CB	7.928	22.768	-6.681	
263	TYR CD1	10.044	24.046	-6.557	
263	TYR CE1	11.333	24.328	-6.168	
263	TYR CZ	11.838	23.618	-5.106	
264	GLY N	6.471	23.161	-8.516	
264	GLY C	8.847	22.196	-8.884	
265	LYS N	8.636	22.477	-8.754	
265	LYS C	8.388	22.232	-11.464	
265	LYS CB	7.788	22.071	-12.044	
265	LYS CD	8.710	20.968	-12.879	
265	LYS NZ	-1.678	20.787	-12.489	
266	GLY CA	7.120	23.612	-11.323	
266	GLY O	6.177	25.793	-11.648	
267	LEU CA	8.490	26.690	-13.097	
267	LEU O	7.953	25.909	-15.298	
267	LEU CG	10.432	28.060	-14.059	
267	LEU CD2	11.924	27.921	-14.327	
268	ILE CA	6.406	28.835	-15.966	
268	ILE O	8.939	28.793	-16.912	
268	ILE CG1	6.099	30.541	-15.952	
268	ILE CD1	8.399	31.765	-16.262	
253	THR N	9.818	22.885	-18.923	
253	THR C	5.281	23.247	-18.818	
253	THR CB	4.084	23.672	-20.952	
253	THR CG2	3.147	25.130	-22.832	
254	THR CA	6.216	23.612	-16.588	
254	THR O	7.402	21.980	-17.895	
254	THR OG1	5.129	22.178	-15.868	
255	THR N	8.499	23.296	-16.876	
255	THR C	9.621	22.031	-16.414	
255	THR CB	11.980	23.455	-19.897	
255	THR CG2	12.286	22.628	-19.606	
256	LYS CA	9.364	20.063	-13.810	
256	LYS O	11.662	20.274	-12.992	
256	LYS CG	9.018	17.805	-11.921	
256	LYS CE	10.212	16.940	-10.623	
257	LEU N	10.212	20.474	-18.824	
257	LEU C	11.230	20.232	-8.614	
257	LEU CB	11.387	22.547	-9.822	
257	LEU CD1	11.245	24.883	-8.921	
258	GLY N	10.431	19.282	-8.298	
258	GLY C	9.168	18.783	-6.373	
259	ASP N	9.826	18.282	-5.180	
259	ASP C	6.639	18.941	-6.709	
259	ASP CB	7.996	17.940	-3.853	
259	ASP OD1	8.611	17.527	-2.354	
260	SER N	5.860	18.610	-5.312	
260	SER C	4.046	20.362	-6.289	
260	SER CB	3.845	18.819	-6.289	
261	PHE N	4.241	19.778	-3.112	
261	PHE C	4.564	21.846	-1.863	
261	PHE CB	4.053	19.749	-0.983	
261	PHE CD1	2.296	20.163	1.125	
261	PHE CE1	1.737	20.717	2.315	
261	PHE CZ	2.605	21.465	3.114	
262	TYR CA	6.688	22.914	-2.251	
262	TYR O	7.201	24.853	-3.393	
262	TYR CG	8.166	21.892	-0.454	
262	TYR CD2	8.149	22.669	0.698	
262	TYR CE2	8.314	22.069	1.962	
262	TYR OH	7.965	20.029	3.205	
263	TYR CA	6.812	23.655	-6.822	
263	TYR O	9.781	24.117	-8.111	
263	TYR CG	9.279	23.035	-6.868	
263	TYR CD2	9.800	22.342	-4.995	
263	TYR CE2	11.082	22.640	-4.691	
263	TYR OH	11.885	23.969	-4.897	
264	GLY CA	3.301	23.064	-7.612	
264	GLY O	4.647	21.274	-8.369	
265	LYS CA	3.834	23.798	-10.971	
265	LYS O	3.684	21.863	-12.384	
265	LYS CG	1.480	21.963	-11.305	
265	LYS CE	-0.692	20.696	-11.391	
266	GLY N	5.787	23.226	-10.817	
266	GLY C	7.193	25.852	-11.818	
267	LEU N	8.262	25.336	-12.480	
267	LEU C	7.804	26.771	-14.637	
267	LEU CB	10.010	26.995	-13.214	
267	LEU CD1	10.896	29.331	-13.890	
268	ILE N	7.064	27.863	-14.632	
268	ILE C	7.426	28.266	-17.065	
268	ILE CB	8.969	29.210	-15.899	
268	ILE CG2	4.243	28.925	-16.867	
269	ASN N	7.887	27.843	-18.237	

269	ASN	CA	7.302	27.973	-19.459
269	ASN	O	8.965	29.962	-20.942
269	ASN	CG	9.161	26.524	-21.235
269	ASN	ND2	10.033	28.796	-21.472
270	VAL	CA	8.863	28.418	-23.034
270	VAL	O	8.057	24.969	-23.872
270	VAL	CG1	6.849	32.797	-22.979
271	GLN	N	7.325	29.701	-22.832
271	GLN	C	6.869	27.934	-25.531
271	GLN	CB	9.104	25.220	-24.964
271	GLN	CD	10.901	28.365	-24.882
271	GLN	NE2	11.702	28.353	-23.510
272	ALA	CA	6.224	25.712	-24.149
272	ALA	O	3.878	25.503	-23.062
273	ALA	N	4.247	26.061	-23.238
273	ALA	C	2.081	27.328	-24.020
273	ALA	CB	2.736	27.773	-21.905
274	ALA	CB	2.952	33.391	-24.210
274	ALA	C	1.730	21.367	-27.096
275	GLN	N	2.330	27.146	-27.814
275	GLN	C	2.147	27.261	-27.777
275	GLN	OT	2.193	27.361	-30.593
275	GLN	CG	0.591	24.604	-27.467
275	GLN	OE1	-1.376	23.893	-28.729

269	ASN	C	8.839	28.916	-20.686
269	ASN	CB	0.687	26.653	-19.896
269	ASN	OD1	8.993	27.826	-18.122
270	VAL	N	8.908	29.868	-20.724
270	VAL	C	6.889	30.807	-21.854
270	VAL	CB	8.656	31.910	-21.622
270	VAL	CG2	6.620	32.362	-22.232
271	GLN	CA	7.603	29.370	-26.766
271	GLN	O	6.233	27.806	-26.091
271	GLN	CG	9.486	28.610	-26.336
271	GLN	OE1	11.369	28.379	-27.718
272	ALA	N	6.977	28.909	-26.892
272	ALA	C	6.701	28.958	-24.246
272	ALA	CB	6.963	26.962	-23.172
273	ALA	CA	3.840	26.721	-22.654
273	ALA	O	0.899	27.219	-14.885
274	ALA	N	3.785	28.464	-26.962
274	ALA	CA	2.199	29.166	-28.067
274	ALA	O	0.980	28.969	-27.021
275	GLN	CA	2.848	26.809	-28.827
275	GLN	O	3.260	27.807	-29.916
275	GLN	CB	0.836	25.724	-28.820
275	GLN	CD	-3.023	23.986	-27.632
275	GLN	NE2	-3.373	23.611	-26.638

The above structural studies together with the kinetic data presented herein and elsewhere (Philipp, M., et al. (1983) Mol. Cell. Biochem. 51, 5-32; Svendsen, I.B. (1976) Carlsberg Res. Comm. 41, 237-291; Markland, S.F. Id; Stauffe, D.C., et al. (1965) J. Biol. Chem. 244, 5333-5338) indicate that the subsites in the binding cleft of subtilisin are capable of interacting with substrate amino acid residues from P-4 to P-2'.

The most extensively studied of the above residues are Gly166, Gly169 and Ala152. These amino acids were identified as residues within the S-1 subsite. As seen in Fig. 3, which is a stereoview of the S-1 subsite, Gly166 and Gly169 occupy positions at the bottom of the S-1 subsite, whereas Ala152 occupies a position near the top of S-1, close to the catalytic Ser221.

All 19 amino acid substitutions of Gly166 and Gly169 have been made. As will be indicated in the examples which follow, the preferred replacement amino acids for Gly166 and/or Gly169 will depend on the specific amino acid occupying the P-1 position of a given substrate.

The only substitutions of Ala152 presently made and analyzed comprise the replacement of Ala152 with Gly and Ser. The results of these substitutions on P-1 specificity will be presented in the examples.

In addition to those residues specifically associated with specificity for the P-1 substrate amino acid, Tyr104 has been identified as being involved with P-4 specificity. Substitutions at Phe189 and Tyr217,

however, are expected to respectively effect P-2' and P-1' specificity.

The catalytic activity of subtilisin has also been modified by single amino acid substitutions at Asn155. The catalytic triad of subtilisin is shown in Fig. 4. As can be seen, Ser221, His64 and Asp32 are positioned to facilitate nucleophilic attach by the serine hydoxylate on the carbonyl of the scissile peptide bond. Crystallographic studies of subtilisin (Robertus, et al. (1972) Biochem. 11, 4293-4303; Matthews, et al. (1975) J. Biol. Chem. 250, 7120-7126; Poulos, et al. (1976) J. Biol. Chem. 250, 1097-1103) show that two hydrogen bonds are formed with the oxyanion of the substrate transition state. One hydrogen bond donor is from the catalytic serine-221 main-chain amide while the other is from one of the NE2 protons of the asparagine-155 side chain. See Fig. 4.

Asn155 was substituted with Ala, Asp, His, Glu and Thr. These substitutions were made to investigate the the stabilization of the charged tetrahedral intermediate of the transition state complex by the potential hydrogen bond between the side chain of Asn155 and the oxyanion of the intermediate. These particular substitutions caused large decreases in substrate turnover, kcat (200 to 4,000 fold), marginal decreases in substrate binding Km (up to 7 fold), and a loss in transition state stabilization energy of 2.2 to 4.7 kcal/mol. The retention of Km and the drop in kcat will make these mutant enzymes useful as binding proteins for specific peptide sequences, the nature of which will be determined by the specificity of the precursor protease.

Various other amino acid residues have been identified which affect alkaline stability. In some cases, mutants having altered alkaline stability also have altered thermal stability.

In B amyloliquefaciens subtilisin residues Asp36, Ile107, Lys170, Ser204 and Lys213 have been identified as residues which upon substitution with a different amino acid alter the alkaline stability of the mutated enzyme as compared to the precursor enzyme. The substitution of Asp36 with Ala and the substitution of Lys170 with Glu each resulted in a mutant enzyme having a lower alkaline stability as compared to the wild type subtilisin. When Ile107 was substituted with Val, Ser204 substituted with Cys, Arg or Leu or Lys213 substituted with Arg, the mutant subtilisin had a greater alkaline stability as compared to the wild type subtilisin. However, the mutant Ser204P demonstrated a decrease in alkaline stability.

In addition, other residues, identified as being associated with the modification of other properties of subtilisin, also affect alkaline stability. These residues include Ser24, Met50, Glu156, Gly166, Gly169 and Tyr217. Specifically the following particular substitutions result in an increased alkaline stability: Ser24C, Met50F, Gly156Q or S, Gly166A, H, K, N or Q, Gly169S or A, and Tyr217F, K, R or L. The mutant Met50V, on the other hand, results in a decrease in the alkaline stability of the mutant subtilisin as compared to wild type subtilisin.

Other residues involved in alkaline stability based on the alkaline stability screen include Asp197 and Met222. Particular mutants include Asp197(R or A) and Met 222 (all other amino acids).

Various other residues have been identified as being involved in thermal stability as determined by the thermal stability screen herein. These residues include the above identified residues which effect alkaline stability and Met199 and Tyr21. These latter two residues are also believed to be important for alkaline stability. Mutants at these residues include I199 and F21.

The amino acid sequence of B. amyloliquefaciens subtilisin has also been modified by substituting two or more amino acids of the wild-type sequence. Six categories of multiply substituted mutant subtilisin have been identified. The first two categories comprise thermally and oxidatively stable mutants. The next three other categories comprise mutants which combine the useful properties of any of several single mutations of B. amyloliquefaciens subtilisin. The last category comprises mutants which have modified alkaline and/or thermal stability.

The first category comprises double mutants in which two cysteine residues have been substituted at various amino acid residue positions within the subtilisin molecule. Formation of disulfide bridges between the two substituted cysteine residues results in mutant subtilisins with altered thermal stability and catalytic activity. These mutants include A21/C22/C87 and C24/C87 which will be described in more detail in Example 11.

The second category of multiple subtilisin mutants comprises mutants which are stable in the presence of various oxidizing agents such as hydrogen peroxide or peracids. Examples 1 and 2 describe these mutants

which include F50/I124/Q222, F50/I124, F50/Q222, F50/L124/Q222, I124/Q222 and L124/Q222.

The third category of multiple subtilisin mutants comprises mutants with substitutions at position 222 combined with various substitutions at positions 166 or 169. These mutants, for example, combine the property of oxidative stability of the A222 mutation with the altered substrate specificity of the various 166 or 169 substitutions. Such multiple mutants include A166/A222, A166/C222, F166/C222, K166/A222, K166/C222, V166/A222 and V166/C222. The K166/A222 mutant subtilisin, for example, has a kcat/Km ratio which is approximately two times greater than that of the single A222 mutant subtilisin when compared using a substrate with phenylalanine as the P-1 amino acid. This category of multiple mutant is described in more detail in Example 12.

The fourth category of multiple mutants combines substitutions at position 156 (Glu to Q or S) with the substitution of Lys at position 166. Either of these single mutations improve enzyme performance upon substrates with glutamate as the P-1 amino acid. When these single mutations are combined, the resulting multiple enzyme mutants perform better than either precursor. See Example 9.

The fifth category of multiple mutants contain the substitution of up to four amino acids of the B. amyloliquefaciens subtilisin sequence. These mutants have specific properties which are virtually identicle to the properties of the subtilisin from B. licheniformis. The subtilisin from B. licheniformis differs from B. amyloliquefaciens subtilisin at 87 out of 275 amino acids. The multiple mutant

F50/S156/A169/L217 was found to have similar substrate specificity and kinetics to the licheniformis enzyme. (See Example 13.) However, this is probably due to only three of the mutations (S156, A169 and L217) which are present in the substrate binding region of the enzyme. It is quite surprising that, by making only three changes out of the 87 different amino acids between the sequence of the two enzymes, the B. amyloliquifaciens enzyme was converted into an enzyme with properties similar to B. licheniformis enzyme. Other enzymes in this series include F50/Q156/N166/L217 and F50/S156/L217.

The sixth category of multiple mutants includes the combination of substitutions at position 107 (Ile to V) with the substitution of Lys at position 213 with Arg, and the combination of substitutions of position 204 (preferably Ser to C or L but also to all other amino acids) with the substituion of Lys at position 213 with R. Other multiple mutants which have altered alkaline stability include Q156/K166, Q156/N166, S156/K166, S156/N166 (previously identified as having altered substrate specificity), and F50/S156/A169/L217 (previously identified as a mutant of B. amyloliquifaciens subtilisin having properties similar to subtilisin from B. licheniformis). The mutant F50/V107/R213 was constructed based on the observed increase in alkaline stability for the single mutants F50, V107 and R213. It was determined that the V107/R213 mutant had an increased alkaline stability as compared to the wild type subtilisin. In this particular mutant, the increased alkaline stability was the result of the cumulative stability of each of the individual mutations. Similarly, the mutant F50/V107/R213 had an even greater alkaline stability as compared to the V107/R213 mutant indicating that

the increase in the alkaline stability due to the F50 mutation was also cumulative.

Table IV summarizes the multiple mutants which have been made including those not mentioned above.

In addition, based in part on the above results, substitution at the following residues in subtilisin is expected to produce a multiple mutant having increased thermal and alkaline stability: Ser24, Met50, Ile107, Glu156, Gly166, Gly169, Ser204, Lys213, Gly215, and Tyr217.

TABLE IV

Double Mutants	Triple, Quadruple or Other Multiple
C22/C87	F50/I124/Q222
C24/C87	F50/L124/Q222
V45/V48	F50/L124/A222
C49/C94	A21/C22/C87
C49/C95	F50/S156/N166/L217
C50/C95	F50/Q156/N166/L217
C50/C110	F50/S156/A169/L217
F50/I124	F50/S156/L217
F50/Q222	F50/Q156/K166/L217
I124/Q222	F50/S156/K166/L217
Q156/D166	F50/Q156/K166/K217
Q156/K166	F50/S156/K166/K217
Q156/N166	F50/V107/R213
S156/D166	[S153/S156/A158/G159/S160/Δ161-164/I165/S166/A169/R170]
S156/K166	L204/R213
S156/N166	R213/204A, E, Q, D, N, G, K, V, R, T, P, I, M, F, Y, W or H
S156/A169	V107/R213
A166/A222	
A166/C222	
F166/A222	
F166/C222	
K166/A222	
K166/C222	
V166/A222	
V166/C222	
A169/A222	
A169/A222	
A169/C222	
A21/C22	

In addition to the above identified amino acid residues, other amino acid residues of subtilisin are

also considered to be important with regard to substrate specificity. Mutation of each of these residues is expected to produce changes in the substrate specificity of subtilisin. Moreover, multiple mutations among these residues and among the previously identified residues are also expected to produce subtilisin mutants having novel substrate specificity.

Particularly important residues are His67, Ile107, Leu126 and Leu135. Mutation of His67 should alter the S-1' subsite, thereby altering the specificity of the mutant for the P-1' substrate residue. Changes at this position could also affect the pH activity profile of the mutant. This residue was identified based on the inventor's substrate modeling from product inhibitor complexes.

Ile107 is involved in P-4 binding. Mutation at this position thus should alter specificity for the P-4 substrate residue in addition to the observed effect on alkaline stability. Ile107 was also identified by molecular modeling from product inhibitor complexes.

The S-2 binding site includes the Leu126 residue. Modification at this position should therefore affect P-2 specificity. Moreover, this residue is believed to be important to convert subtilisin to an amino peptidase. The pH activity profile should also be modified by appropriate substitution. These residues were identified from inspection of the refined model, the three dimensional structure from modeling studies. A longer side chain is expected to preclude binding of any side chain at the S-2 subsite. Therefore, binding would be restricted to subsites S-1, S-1', S-2', S-3'

and cleavage would be forced to occur after the amino terminal peptide.

Leu135 is in the S-4 subsite and if mutated should alter substrate specificity for P-4 if mutated. This residue was identified by inspection of the three-dimensional structure and modeling based on the product inhibitor complex of F222.

In addition to these sites, specific amino acid residues within the segments 97-103, 126-129 and 213-215 are also believed to be important to substrate binding.

Segments 97-103 and 126-129 form an antiparallel beta sheet with the main chain of substrate residues P-4 through P-2. Mutating residues in those regions should affect the substrate orientation through main chain (enzyme) - main chain (substrate) interactions, since the main chain of these substrate residues do not interact with these particular residues within the S-4 through S-2 subsites.

Within the segment 97-103, Gly97 and Asp99 may be mutated to alter the position of residues 101-103 within the segment. Changes at these sites must be compatible, however. In B. amyloliquifaciens subtilisin Asp99 stabilizes a turn in the main chain tertiary folding that affects the direction of residues 101-103. B. licheniformis subtilisin Asp97, functions in an analogous manner.

In addition to Gly97 and Asp99, Ser101 interacts with Asp99 in B. amyliquefaciens subtilisin to stabilize the same main chain turn. Alterations at this residue should alter the 101-103 main chain direction.

Mutations at Glu103 are also expected to affect the 101-103 main chain direction.

The side chain of Gly102 interacts with the substrate P-3 amino acid. Side chains of substituted amino acids thus are expected to significantly affect specificity for the P-3 substrate amino acids.

All the amino acids within the 127-129 segment are considered important to substrate specificity. Gly 127 is positioned such that its side chain interacts with the S-1 and S-3 subsites. Altering this residue thus should alter the specificity for P-1 and P-3 residues of the substrate.

The side chain of Gly128 comprises a part of both the S-2 and S-4 subsites. Altered specificity for P-2 and P-4 therefore would be expected upon mutation. Moreover, such mutation may convert subtilisin into an amino peptidase for the same reasons substitutions of Leu126 would be expected to produce that result.

The Pro129 residue is likely to restrict the conformational freedom of the sequence 126-133, residues which may play a major role in determining P-1 specificity. Replacing Pro may introduce more flexibility thereby broadening the range of binding capabilities of such mutants.

The side chain of Lys213 is located within the S-3 subsite. All of the amino acids within the 213-215 segment are also considered to be important to substrate specificity. Accordingly, altered P-3 substrate specificity is expected upon mutation of this residue.

The Tyr214 residue does not interact with substrate but is positioned such that it could affect the conformation of the hair pin loop 204-217.

Finally, mutation of the Gly215 residue should affect the S-3' subsite, and thereby alter P-3' specificity.

In addition to the above substitutions of amino acids, the insertion or deletion of one or more amino acids within the external loop comprising residues 152-172 may also affect specificity. This is because these residues may play a role in the "secondary contact region" described in the model of streptomyces subtilisin inhibitor complexed with subtilisin. Hirono, et al. (1984) J. Mol. Biol. 178, 389-413. Thermitase K has a deletion in this region, which eliminates several of these "secondary contact" residues. In particular, deletion of residues 161 through 164 is expected to produce a mutant subtilisin having modified substrate specificity. In addition, a rearrangement in this area induced by the deletion should alter the position of many residues involved in substrate binding, predominantly at P-1. This, in turn, should affect overall activity against proteinaceous substrates.

The effect of deletion of residues 161 through 164 has been shown by comparing the activity of the wild type (WT) enzyme with a mutant enzyme containing this deletion as well as multiple substitutions (i.e., S153/S156/A158/G159/S160/Δ161-164/I165/S166/A169/R170). This produced the following results:

TABLE V

	kcat	Km	kcat/Km
WT	50	1.4×10^{-4}	3.6×10^{5}
Deletion mutant	8	5.0×10^{-6}	1.6×10^{6}

The WT has a kcat 6 times greater than the deletion mutant but substrate binding is 28 fold tighter by the deletion mutant. The overall efficiency of the deletion mutant is thus 4.4 times higher than the WT enzyme.

All of these above identified residues which have yet to be substituted, deleted or inserted into are presented in Table VI.

TABLE VI

Substitution/Insertion/Deletion

Residues

His67	Ala152
Leu126	Ala153
Leu135	Gly154
Gly97	Asn155
Asp99	Gly156
Ser101	Gly157
Gly102	Gly160
Glu103	Thr158
Leu126	Ser159
Gly127	Ser161
Gly128	Ser162
Pro129	Ser163
Tyr214	Thr164
Gly215	Val165
Gly166	Gly169
Tyr167	Lys170
Pro168	Tyr171
	Pro172

The following disclosure is intended to serve as a representation of embodiments herein, and should not be construed as limiting the scope of this application. These specific examples disclose the construction of certain of the above identified mutants. The construction of the other mutants, however, is apparent from the disclosure herein and that presented in EPO Publication No. 0130756.

All literature citations are expressly incorporated by reference.

EXAMPLE 1

Identification of Peracid Oxidizable Residues of Subtilisin Q222 and L222

As shown in Figures 6A and 6B, organic peracid oxidants inactivate the mutant subtilisins Met222L and Met222Q (L222 and Q222). This example describes the identification of peracid oxidizable sites in these mutant subtilisins.

First, the type of amino acid involved in peracid oxidation was determined. Except under drastic conditions (Means, G.E., et al. (1971) Chemical Modifications of Proteins, Holden-Day, S.F., CA, pp. 160-162), organic peracids modify only methionine and tryptophan in subtilisin. Difference spectra of the enzyme over the 250nm to 350nm range were determined during an inactivation titration employing the reagent, diperdodecanoic acid (DPDA) as oxidant. Despite quantitative inactivation of the enzyme, no change in absorbance over this wavelength range was noted as shown in Figures 7A and 7B indicating that tryptophan was not oxidized. Fontana, A., et al. (1980) Methods in Peptide and Protein Sequence

Analysis (C. Birr ed.) Elsevier, New York, p. 309. The absence of tryptophan modification implied oxidation of one or more of the remaining methionines of B. amyloliquefaciens subtilisin. See Figure 1.

To confirm this result the recombinant subtilisin Met222F was cleaved with cyanogen bromide (CNBr) both before and after oxidation by DPDA. The peptides produced by CNBr cleavage were analyzed on high resolution SDS-pyridine peptide gels (SPG).

Subtilisin Met222F (F222) was oxidized in the following manner. Purified F222 was resuspended in 0.1 M sodium borate pH 9.5 at 10 mg/ml and was added to a final concentration of 26 diperdodecanoic acid (DPDA) at 26 mg/ml was added to produce an effective active oxygen concentration of 30 ppm. The sample was incubated for at least 30 minutes at room temperature and then quenched with 0.1 volume of 1 M Tris pH 8.6 buffer to produce a final concentration of 0.1 M Tris pH 8.6). 3mM phenylmethylsulfonyl fluoride (PMSF) was added and 2.5 ml of the sample was applied to a Pharmacia PD10 column equilibrated in 10 mM sodium phosphate pH 6.2, 1 mM PMSF. 3.5 ml of 10 mM sodium phosphate pH6.2, 1mM PMSF was applied and the eluant collected.

F222 and DPDA oxidized F222 were precipitated with 9 volumes of acetone at -20°C. The samples were resuspended at 10 mg/ml in 8M urea in 88% formic acid and allowed to sit for 5 minutes. An equal volume of 200 mg/ml CNBr in 88% formic acid was added (5 mg/ml protein) and the samples incubated for 2 hours at room temperature in the dark. Prior to gel electrophoresis, the samples were lyophilized and resuspended at 2-5 mg/ml in sample buffer (1%

pyridine, 5% $NaDodSO_4$, 5% glycerol and bromophenol blue) and disassociated at 95°C for 3 minutes.

The samples were electrophoresed on discontinuous polyacrylamide gels (Kyte, J., et al. (1983) Anal. Bioch. 133, 515-522). The gels were stained using the Pharmacia silver staining technique (Sammons, D.W., et al. (1981) Electrophoresis 2 135-141).

The results of this experiment are shown in Figure 8. As can be seen, F222 treated with CNBr only gives nine resolved bands on SPG. However, when F222 is also treated with DPDA prior to cleavage, bands X, 7 and 9 disappear whereas bands 5 and 6 are greatly increased in intensity.

In order to determine which of the methionines were effected, each of the CNBr peptides was isolated by reversed phase HPLC and further characterized. The buffer system in both Solvent A (aqueous) and Solvent B (organic) for all HPLC separations was 0.05% triethylamime/trifloroacetic acid (TEA-TFA). In all cases unless noted, solvent A consisted of 0.05% TEA-TFA in H_2O, solvent B was 0.05% TEA-TFA in 1-propanol, and the flow rate was 0.5 ml/minute.

For HPLC analysis, two injections of 1 mg enzyme digest were used. Three samples were acetone precipitated, washed and dried. The dried 1 mg samples were resuspended at 10 mg/ml in 8M urea, 88% formic acid; an equal volume of 200 mg/ml CNBr in 88% formic acid was added (5 mg/ml protein). After incubation for 2 hours in the dark at room temperature, the samples were desalted on a 0.8 cm X 7

cm column of Tris Acryl GF05 coarse resin (IBF, Paris, France) equilibrated with 40% solvent B, 60% solvent A. 200 ul samples were applied at a flow rate of 1 ml a minute and 1.0-1.2 ml collected by monitoring the absorbance at 280nm. Prior to injection on the HPLC, each desalted sample was diluted with 3 volumes of solvent A. The samples were injected at 1.0 ml/min (2 minutes) and the flow then adjusted to 0.5 ml/min (100% A). After 2 minutes, a linear gradient to 60% B at 1.0% B/min was initiated. From each 1 mg run, the pooled peaks were sampled (50ul) and analyzed by gel electrophoresis as described above.

Each polypeptide isolated by reversed phase HPLC was further analyzed for homogeneity by SPG. The position of each peptide on the known gene sequence (Wells, J.A., et al. (1983) Nucleic Acids Res. 11 7911-7924) was obtained through a combination of amino acid compositional analysis and, where needed, amino terminal sequencing.

Prior to such analysis the following peptides were to rechromatographed.

1. CNBr peptides from F222 not treated with DPDA:

Peptide 5 was subjected to two additional reversed phase separations. The 10 cm C4 column was equilibrated to 80%A/ 20%B and the pooled sample applied and washed for 2 minutes. Next an 0.5% ml B/min gradient was initiated. Fractions from this separation were again rerun, this time on the 25 cm C4 column, and employing 0.05% TEA-TFA in acetonitrile/1-propanol (1:1) for solvent B. The gradient was identical to the one just described.

Peptide "X" was subjected to one additional separation after the initial chromatography. The sample was applied and washed for 2 minutes at 0.5ml/min (100%A), and a 0.5% ml B/min gradient was initiated.

Peptides 7 and 9 were rechromatographed in a similar manner to the first rerun of peptide 5.

Peptide 8 was purified to homogeneity after the initial separation.

2. CNBr Peptides from DPDA Oxidized F222:

Peptides 5 and 6 from a CNBr digest of the oxidized F222 were purified in the same manner as peptide 5 from the untreated enzyme.

Amino acid compositional analysis was obtained as follows. Samples (~1nM each amino acid) were dried, hydrolyzed in vacuo with 100 ul 6N HCl at 106°C for 24 hours and then dried in a Speed Vac. The samples were analyzed on a Beckmann 6300 AA analyzer employing ninhydrin detection.

Amino terminal sequence data was obtained as previously described (Rodriguez, H., et al. (1984) Anal. Biochem. 134, 538-547).

The results are shown in Table VII and Figure 9.

TABLE VII

Amino and COOH terminii of CNBr fragments

	Terminus and Method	
Fragment	amino, method	COOH, method
X	1, sequence	50, composition
9	51, sequence	119, composition
7	125, sequence	199, composition
8	200, sequence	275, composition
5ox	1, sequence	119, composition
6ox	120, composition	199, composition

Peptides 5ox and 6ox refer to peptides 5 and 6 isolated from CNBr digests of the oxidized protein where their respective levels are enhanced.

From the data in Table VII and the comparison of SPG tracks for the oxidized and native protein digests in Figure 8, it is apparent that (1) Met50 is oxidized leading to the loss of peptides X and 9 and the appearance of 5; and (2) Met124 is also oxidized leading to the loss of peptide 7 and the accumulation of peptide 6. Thus oxidation of B. amyloliquifaciens subtilisin with the peracid, diperdocecanoic acid leads to the specific oxidation of methionine at residues 50 and 124.

EXAMPLE 2

Substitution at Met50 and Met124 in Subtilisin Met222Q

The choice of amino acid for substitution at Met50 was based on the available sequence data for subtilisins

from B. licheniformis (Smith, E.C., et al. (1968) J. Biol. Chem. 243, 2184-2191), B.DY (Nedkov, P., et al. (1983) Hoppe Sayler's Z. Physiol. Chem. 364 1537-1540), B. amylosacchariticus (Markland, F.S., et al. (1967) J. Biol. Chem. 242 5198-5211) and B. subtilis (Stahl, M.L., et al. (1984) J. Bacteriol. 158, 411-418). In all cases, position 50 is a phenylalanine. See Figure 5. Therefore, Phe50 was chosen for construction.

At position 124, all known subtilisins possess a methionine. See Figure 5. Molecular modelling of the x-ray derived protein structure was therefore required to determine the most probable candidates for substitution. From all 19 candidates, isoleucine and leucine were chosen as the best residues to employ. In order to test whether or not modification at one site but not both was sufficient to increase oxidative stability, all possible combinations were built on the Q222 backbone (F50/Q222, I124/Q222, F50/I124/Q222).

A. Construction of Mutations Between Codons 45 and 50

All manipulations for cassette mutagenesis were carried out on pS4.5 using methods disclosed in EPO Publication No. 0130756 and Wells, J.A., et al, (1985) Gene 34, 315-323. The pΔ50 in Fig. 10, line 4, mutations was produced using the mutagenesis primer shown in Fig. 10, line 6, and employed an approach designated as restriction-purification which is described below. Briefly, a M13 template containing the subtilisin gene, M13mp11-SUBT was used for heteroduplex synthesis (Adelman, et al (1983), DNA 2, 183-193). Following transfection of JM101 (ATCC 33876), the 1.5 kb EcoRI-BamHI fragment containing the

subtilisin gene was subcloned from M13mp11 SUBT rf into a recipient vector fragment of pBS42 the construction of which is described in EPO Publication No. 0130756. To enrich for the mutant sequence (pΔ50, line 4), the resulting plasmid pool was digested with KpnI, and linear molecules were purified by polyacrylamide gel electrophoresis. Linear molecules were ligated back to a circular form, and transformed into E. coli MM294 cells (ATCC 31446). Isolated plasmids were screened by restriction analysis for the KpnI site. KpnI$^+$ plasmids were sequenced and confirmed the pΔ50 sequence. Asterisks in Figure 11 indicate the bases that are mutated from the wid type sequence (line 4). pΔ50 (line 4) was cut with StuI and EcoRI and the 0.5 Kb fragment containing the 5' half of the subtilisin gene was purified (fragment 1). pΔ50 (line 4) was digested with KpnI and EcoRI and the 4.0 Kb fragment containing the 3' half of the subtilisin gene and vector sequences was purified (fragment 2). Fragments 1 and 2 (line 5), and duplex DNA cassettes coding for mutations desired (shaded sequence, line 6) were mixed in a molar ratio of 1:1:10, respectively. For the particular construction of this example the DNA cassette contained the triplet TTT for codon 50 which encodes Phe. This plasmid was designated pF50. The mutant subtilisin was designated F50.

B. Construction of Mutation Between Codons 122 and 127

The procedure of Example 2A was followed in substantial detail except that the mutagenesis primer of Figure 11, line 7 was used and restriction-purification for the EcoRV site in pΔ124 was used. In addition, the DNA cassette (shaded sequence, Figure

11, line 6) contained the triplet ATT for codon 124 which encodes Ile and CTT for Leu. Those plasmids which contained the substitution of Ile for Met124were designeated pI124. The mutant subtilisin was designated I124.

C. Construction of Various F50/I124/Q222 Multiple Mutants

The triple mutant, F50/I124/Q222, was constructed from a three-way ligation in which each fragment contained one of the three mutations. The single mutant Q222 (pQ222) was prepared by cassette mutagenesis as described in EPO Publication No. 0130756. The F50 mutation was contained on a 2.2kb AvaII to PvuII fragment from pF50; the I124 mutation was contained on a 260 bp PvuII to AvaII fragment from pI124; and the Q222 mutation was contained on 2.7 kb AvaII to AvaII fragment from pQ222. The three fragments were ligated together and transformed into E. coli MM294 cells. Restriction analysis of plasmids from isolated transformants confirmed the construction. To analyze the final construction it was convenient that the AvaII site at position 798 in the wild-type subtilisin gene was eliminated by the I124 construction.

The F50/Q222 and I124/Q222 mutants were constructed in a similar manner except that the appropriate fragment from pS4.5 was used for the final construction.

D. Oxidative Stability of Q222 Mutants

The above mutants were analyzed for stability to peracid oxidation. As shown in Fig. 12, upon incubation with diperdodecanoic acid (protein 2mg/mL, oxidant 75ppm[O]), both the I124/Q222 and the

F50/I124/Q222 are completely stable whereas the F50/Q222 and the Q222 are inactivated. This indicates that conversion of Met124 to I124 in subtilisin Q222 is sufficient to confer resistance to organic peracid oxidants.

EXAMPLE 3

Subtilisin Mutants Having Altered Substrate Specificity-Hydrophobic Substitutions at Residues 166

Subtilisin contains an extended binding cleft which is hydrophobic in character. A conserved glycine at residue 166 was replaced with twelve non-ionic amino acids which can project their side-chains into the S-1 subsite. These mutants were constructed to determine the effect of changes in size and hydrophobicity on the binding of various substrates.

A. Kinetics for Hydrolysis of Substrates Having Altered P-1 Amino Acids by Subtilisin from B. Amyloliquefaciens

Wild-type subtilisin was purified from B. subtilis culture supernatants expressing the B. amyloliquefaciens subtilisin gene (Wells, J.A., et al. (1983) Nucleic Acids Res. 11, 7911-7925) as previously described (Estell, D.A., et al. (1985) J. Biol. Chem. 260, 6518-6521). Details of the synthesis of tetrapeptide substrates having the form succinyl-L-AlaL-AlaL-ProL-[X]-p-nitroanilide (where X is the P1 amino acid) are described by DelMar, E.G., et al. (1979) Anal. Biochem. 99, 316-320. Kinetic parameters, Km(M) and kcat(s^{-1}) were measured using a modified progress curve analysis (Estell, D.A., et al. (1985) J. Biol. Chem. 260, 6518-6521). Briefly, plots

of rate versus product concentration were fit to the differential form of the rate equation using a non-linear regression algorithm. Errors in kcat and Km for all values reported are less than five percent. The various substrates in Table VIII are ranged in order of decreasing hydrophobicity. Nozaki, Y. (1971), J. Biol. Chem. 246, 2211-2217; Tanford C. (1978) Science 200, 1012).

TABLE VIII

P1 substrate Amino Acid	kcat(S^{-1})	1/Km(M^{-1})	kcat/Km ($s^{-1}M^{-1}$)
Phe	50	7,100	360,000
Tyr	28	40,000	1,100,000
Leu	24	3,100	75,000
Met	13	9,400	120,000
His	7.9	1,600	13,000
Ala	1.9	5,500	11,000
Gly	0.003	8,300	21
Gln	3.2	2,200	7,100
Ser	2.8	1,500	4,200
Glu	0.54	32	16

The ratio of kcat/Km (also referred to as catalytic efficienty) is the apparent second order rate constant for the conversion of free enzyme plus substrate (E+S) to enzyme plus products (E+P) (Jencks, W.P., Catalysis in Chemistry and Enzymology (McGraw-Hill, 1969) pp. 321-436; Fersht, A., Enzyme Structure and Mechanism (Freeman, San Francisco, 1977) pp. 226-287). The log (kcat/Km) is proportional to transition state binding

energy, $\Delta G_T^{\neq}$. A plot of the log kcat/Km versus the hydrophobicity of the P1 side-chain (Figure 14) shows a strong correlation ($r = 0.98$), with the exception of the glycine substrate which shows evidence for non-productive binding. These data show that relative differences between transition-state binding energies can be accounted for by differences in P-1 side-chain hydrophobicity. When the transition-state binding energies are calculated for these substrates and plotted versus their respective side-chain hydrophobicities, the line slope is 1.2 (not shown). A slope greater than unity, as is also the case for chymotrypsin (Fersht, A., Enzyme Structure and Mechanism (Freeman, San Francisco, 1977) pp. 226-287; Harper, J.W., et al. (1984) Biochemistry, 23, 2995-3002), suggests that the P1 binding cleft is more hydrophobic than ethanol or dioxane solvents that were used to empirically determine the hydrophobicity of amino acids (Nozaki, Y., et al. J. Biol. Chem. (1971) 246, 2211-2217; Tanford, C. (1978) Science 200, 1012).

For amide hydrolysis by subtilisin, kcat can be interpreted as the acylation rate constant and Km as the dissociation constant, for the Michaelis complex (E·S), Ks. Gutfreund, H., et al (1956) Biochem. J. 63, 656. The fact that the log kcat, as well as log 1/Km, correlates with substrate hydrophobicity is consistent with proposals (Robertus, J.D., et al. (1972) Biochemistry 11, 2439-2449; Robertus, J.D., et al. (1972) Biochemistry 11, 4293-4303) that during the acylation step the P-1 side-chain moves deeper into the hydrophobic cleft as the substrate advances from the Michaelis complex (E·S) to the tetrahedral transition-state complex ($E \cdot S^{\neq}$). However, these data can also be interpreted as the hydrophobicity of the P1 side-chain effecting the orientation, and thus the

susceptibility of the scissile peptide bond to nucleophilic attack by the hydroxyl group of the catalytic Ser221.

The dependence of kcat/Km on P-1 side chain hydrophobicity suggested that the kcat/Km for hydrophobic substrates may be increased by increasing the hydrophobicity of the S-1 binding subsite. To test this hypothesis, hydrophobic amino acid substitutions of Gly166 were produced.

Since hydrophobicity of aliphatic side-chains is directly proportional to side-chain surface area (Rose, G.D., et al. (1985) Science 229, 834-838; Reynolds, J.A., et al. (1974) Proc. Natl. Acad. Sci. USA 71, 2825-2927), increasing the hydrophobicity in the S-1 subsite may also sterically hinder binding of larger substrates. Because of difficulties in predicting the relative importance of these two opposing effects, we elected to generate twelve non-charged mutations at position 166 to determine the resulting specificities against non-charged substrates of varied size and hydrophobicity.

B. Cassette Mutagenesis of the P1 Binding Cleft

The preparation of mutant subtilisims containing the substitution of the hydrophobic amino acids Ala, Val and Phe into residue 166 has been described in EPO Publication No. 0130756. The same method was used to produce the remaining hydrophobic mutants at residue 166. In applying this method, two unique and silent restriction sites were introduced in the subtilisin genes to closely flank the target codon 166. As can be seen in Figure 13, the wild type sequence (line 1)

was altered by site-directed mutagenesis in M13 using the indicated 37mer mutagenesis primer, to introduce a 13 bp delection (dashedline) and unique SacI and XmaI sites (underlined sequences) that closely flank codon 166. The subtilisin gene fragment was subcloned back into the E. coli - B. subtilis shuttle plasmid, pBS42, giving the plasmid pΔ166 (Figure 13, line 2). pΔ166 was cut open with SacI and XmaI, and gapped linear molecules were purified (Figure 13, line 3). Pools of synthetic oligonucleotides containing the mutation of interest were annealed to give duplex DNA cassettes that were ligated into gapped pΔ166 (underlined and overlined sequences in Figure 13, line 4). This construction restored the coding sequence except over position 166(NNN; line 4). Mutant sequences were confirmed by dideoxy sequencing. Asterisks denote sequence changes from the wild type sequence. Plasmids containing each mutant B. amyloliquefaciens subtilisin gene were expressed at roughly equivalent levels in a protease deficient strain of B. subtilis, BG2036 as previously described. EPO Publication No. 0130756; Yang, M., et al. (1984) J. Bacteriol. 160, 15-21; Estell, D.A., et al (1985) J. Biol. Chem. 260, 6518-6521.

C. Narrowing Substrate Specificity by Steric Hindrance

To probe the change in substrate specificity caused by steric alterations in the S-1 subsite, position 166 mutants were kinetically analyzed versus P1 substrates of increasing size (i.e., Ala, Met, Phe and Tyr). Ratios of kcat/Km are presented in log form in Figure 15 to allow direct comparisons of transition-state binding energies between various enzyme-substrate pairs.

According to transition state theory, the free enery difference between the free enzyme plus substrate (E + S) and the transition state complex ($E \cdot S^{\neq}$) can be calculated from equation (1),

(1) $$\Delta G_T^{\neq} = -RT \ln kcat/Km + RT \ln kT/h$$

in which kcat is the turnover number, Km is the Michaelis constant, R is the gas constant, T is the temperature, k is Boltzmann's constant, and h is Planck's constant. Specificity differences are ezpressed quantitatively as differences between transition state binding energies (i.e., $\Delta\Delta G_t^{\neq}$), and can be calculated from equation (2).

(2) $$\Delta\Delta G_T^{\neq} = -RT \ln (kcat/Km)_A/(kcat/Km)_B$$

A and B represent either two different substrates assayed againt the same enzyme, or two mutant enzymes assayed against the same substrate.

As can be seen from Figure 15A, as the size of the side-chain at position 166 increases the substrate preference shifts from large to small P-1 side-chains. Enlarging the side-chain at position 166 causes kcat/Km to decrease in proportion to the size of the P-1 substrate side-chain (e.g., from Gly166 (wild-type) through W166, the kcat/Km for the Tyr substrate is decreased most followed in order by the Phe, Met and Ala P-1 substrates).

Specific steric changes in the position 166 side-chain, such as he presence of a β-hydroxyl group, β- or γ-aliphatic branching, cause large decreases in kcat/Km for larger P1 substrates. Introducing a β-hydroxyl group in going from A166 (Figure 15A) to

S166 (Figure 15B), causes an 8 fold and 4 fold reduction in kcat/Km for Phe and Tyr substrates, respectively, while the values for Ala and Met substrates are unchanged. Producing a β-branched structure, in going from S166 to T166, results in a drop of 14 and 4 fold in kcat/Km for Phe and Tyr, respectively. These differences are slightly magnified for V166 which is slightly larger and isosteric with T166. Enlarging the β-branched substituents from V166 to I166 causes a lowering of kcat/Km between two and six fold toward Met, Phe and Tyr substrates. Inserting a γ-branched structure, by replacing M166 (Figure 15A) with L166 (Figure 15B), produces a 5 fold and 18 fold decrease in kcat/Km for Phe and Tyr substrates, respectively. Aliphatic γ-branched appears to induce less steric hindrance toward the Phe P-1 substrate than β-branching, as evidenced by the 100 fold decrease in kcat/Km for the Phe substrate in going from L166 to I166.

Reductions in kcat/Km resulting from increases in side chain size in the S-1 subsite, or specific structural features such as β- and γ-branching, are quantitatively illustrated in Figure 16. The kcat/Km values for the position 166 mutants determined for the Ala, Met, Phe, and Tyr P-1 substrates (top panel through bottom panel, respectively), are plotted versus the position 166 side-chain volumes (Chothia, C. (1984) Ann. Rev. Biochem. 53, 537-572). Catalytic efficiency for the Ala substrate reaches a maximum for I166, and for the Met substrate it reaches a maximum between V166 and L166. The Phe substrate shows a broad kcat/Km peak but is optimal with A166. Here, the β-branched position 166 substitutions form a line that is parallel to, but roughly 50 fold lower in kcat/Km than side-chains of similar size [i.e., C166 versus

T166, L166 versus I166]. The Tyr substrate is most efficiently utilized by wild type enzyme (Gly166), and there is a steady decrease as one proceeds to large position 166 side-chains. The β-branched and γ-branched substitutions form a parallel line below the other non-charged substitutions of similar molecular volume.

The optimal substitution at position 166 decreases in volume with increasing volume of the P1 substrate [i.e., I166/Ala substrate, L166/Met substrate, A166/Phe substrate, Gly166/Tyr substrate]. The combined volumes for these optimal pairs may approximate the volume for productive binding in the S-1 subsite. For the optimal pairs, Gly166/Tyr substrate, A166/Phe substrate, L166/Met substrate, V166/Met substrate, and I166/Ala substrate, the combined volumes are 266,295,313,339 and 261 A^3, respectively. Subtracting the volume of the peptide backbone from each pair (i.e., two times the volume of glycine), an average side-chain volume of $160\pm32A^3$ for productive binding can be calculated.

The effect of volume, in excess to the productive binding volume, on the drop in transition-state binding energy can be estimated from the Tyr substrate curve (bottom panel, Figure 16), because these data, and modeling studies (Figure 2), suggest that any substitution beyond glycine causes steric repulsion. A best-fit line drawn to all the data ($r = 0.87$) gives a slope indicating a loss of roughly 3 kcal/mol in transition state binding energy per $100A^3$ of excess volume. ($100A^3$ is approximately the size of a leucyl side-chain.)

D. Enhanced Catalytic Efficiency Correlates with Increasing Hydrophobicity of the Position 166 Substitution

Substantial increases in kcat/Km occur with enlargement of the position 166 side-chain, except for the Tyr P-1 substrate (Figure 16). For example, kcat/Km increases in progressing from Gly166 to I166 for the Ala substrate (net of ten-fold), from Gly166 to L166 for the Met substrate (net of ten-fold) and from Gly166 to A166 for the Phe substrate (net of two-fold). The increases in kcat/Km cannot be entirely explained by the attractive terms in the van der Waals potential energy function because of their strong distance dependence ($1/r^6$) and because of the weak nature of these attractive forces (Jencks, W.P., Catalysis in Chemistry and Enzymology (McGraw-Hill, 1969) pp. 321-436; Fersht, A., Enzyme Structure and Mechanism (Freeman, San Francisco, 1977) pp. 226-287; Levitt, M. (1976) J. Mol. Biol. 104, 59-107). For example, Levitt (Levitt, M. (1976) J. Mol. Biol. 104, 59-107) has calculated that the van der Waals attraction between two methionyl residues would produce a maximal interaction energy of roughly -0.2 kcal/mol. This energy would translate to only 1.4 fold increase in kcat/Km.

The increases of catalytic efficiency caused by side-chain substitutions at position 166 are better accounted for by increases in the hydrophobicity of the S-1 subsite. The increase kcat/Km observed for the Ala and Met substrates with increasing position 166 side-chain size would be expected, because hydrophobicity is roughly proportional to side-chain surface area (Rose, G.D., et al. (1985) Science 229, 834-838; Reynolds, J.A., et al. (1974) Proc. Natl. Acad. Sci. USA 71, 2825-2927).

Another example that can be interpreted as a hydrophobic effect is seen when comparing kcat/Km for isosteric substitutions that differ in hydrophobicity such as S166 and C166 (Figure 16). Cysteine is considerably more hydrophobic than serine (-1.0 versus +0.3 kcal/mol) (Nozaki, Y., et al. (1971) J. Biol. Chem. 246, 2211-2217; Tanford, C. (1978) Science 200, 1012). The difference in hydrophobicity correlates with the observation that C166 becomes more efficient relative to Ser166 as the hydrophobicity of the substrates increases (i.e., Ala < Met < Tye < Phe). Steric hindrance cannot explain these differences because serine is considerably smaller than cysteine (99 versus 118A^3). Paul, I.C., Chemistry of the -SH Group (ed. S. Patai, Wiley Interscience, New York, 1974) pp. 111-149.

E. Production of an Elastase-Like Specificity in Subtilisin

The I166 mutation illustrates particularly well that large changes in specificity can be produced by altering the structure and hydrophobicity of the S-1 subsite by a single mutation (Figure 17). Progressing through the small hydrophobic substrates, a maximal specificity improvement over wild type occurs for the Val substrate (16 fold in kcat/Km). As the substrate side chain size increases, these enhancements shrink to near unity (i.e., Leu and His substrates). The I166 enzyme becomes poorer against larger aromatic substrates of increasing size (e.g., I166 is over 1,000 fold worse against the Tyr substrate than is Gly166). We interpret the increase in catalytic efficiency toward the small hydrophobic substrates for I166 compared to Gly166 to the greater hydrophobicity of isoluecine (i.e., -1.8 kcal/mol versus 0). Nozaki,

Y., et al. (1971) J. Biol. Chem. 246, 2211-2217; Tanford, C. (1978) Science 200, 1012. The decrease in catalytic efficiency toward the very large substrates for I166 versus Gly166 is attributed to steric repulsion.

The specificity differences between Gly166 and I166 are similar to the specificity differences between chymotrypsin and the evolutionary relative, elastase (Harper, J.W., et al (1984) Biochemistry 23, 2995-3002). In elastase, the bulky amino acids, Thr and Val, block access to the P-1 binding site for large hydrophobic substrates that are preferred by chymotrypsin. In addition, the catalytic efficiencies toward small hydrophobic substrates are greater for elastase than for chymotrypsin as we obeseve for I166 versus Gly166 in subtilisin.

EXAMPLE 4

Substitution of Ionic Amino Acids for Gly166

The construction of subtilisin mutants containing the substitution of the ionic amino acids Asp, Asn, Gln, Lys and Ang are disclosed in EPO Publication No. 0130756. The present example describes the construction of the mutant subtilisin containing Glu at position 166 (E166) and presents substrate specificity data on these mutants. Further data on position 166 and 156 single and double mutants is presented infra.

pΔ166, described in Example 3, was digested with SacI and XmaI. The double strand DNA cassette (underlined and overlined) of line 4 in Figure 13 contained the

triplet GAA for the codon 166 to encode the replacement of Glu for Gly166. This mutant plasmid designated pQ166 was propagated in BG2036 as described. This mutant subtilisin, together with the other mutants containing ionic substituent amino acids at residue 166, were isolated as described and further analyzed for variations in substrate specificity.

Each of these mutants was analyzed with the tetrapeptide substrates, succinyl-L-AlaL-AlaProL-X--p-nitroanilide, where X was Phe, Ala and Glu.

The results of this analysis are shown in Table IX.

TABLE IX

	P-1 Substrate (kcat/Km x 10^{-4})		
Position 166	Phe	Ala	Glu
Gly (wild type)	36.0	1.4	0.002
Asp (D)	0.5	0.4	<0.001
Glu (E)	3.5	0.4	<0.001
Asn (N)	18.0	1.2	0.004
Gln (Q)	57.0	2.6	0.002
Lys (K)	52.0	2.8	1.2
Arg (R)	42.0	5.0	0.08

These results indicate that charged amino acid substitutions at Gly166 have improved catalytic efficiencies (kcat/Km) for oppositely charged P-1 substrates (as much as 500 fold) and poorer catalytic efficiency for like charged P-1 substrates.

EXAMPLE 5

Substitution of Glycine at Position 169

The substitution of Gly169 in B. amyloliquefaciens subtilisin with Ala and Ser is described in EPO Publication No. 0130756. The same method was used to make the remaining 17 mutants containing all other substituent amino acids for position 169.

The construction protocol is summarized in Figure 18. The overscored and underscored double stranded DNA cassettes used contained the following triplet encoding the substitution of the indicated amino acid at residue 169.

GCT	A	ATG	M
TGT	C	AAC	N
GAT	D	CCT	P
GAA	E	CAA	Q
TTC	F	AGA	R
GGC	G	AGC	S
CAC	H	ACA	T
ATC	I	GTT	V
AAA	K	TGG	W
CTT	L	TAC	Y

Each of the plasmids containing a substituted Gly169 was designated pX169, where X represents the substituent amino acid. The mutant subtilisins were simialrly designated.

Two of the above mutant subtilisins, A169 and S169, were analyzed for substrate specificity against synthetic substrates containing Phe, Leu, Ala and Arg in the P-1 position. The following results are shown in Table X.

TABLE X

Effect of Serine and Alanine Mutations at Position 169 on P-1 Substrate Specificity

	P-1 Substrate (kcat/Km x 10^{-4})			
Position 169	Phe	Leu	Ala	Arg
Gly (wild type)	40	10	1	0.4
A169	120	20	1	0.9
S169	50	10	1	0.6

These results indicate that substitutions of Ala and Ser at Gly169 have remarkably similar catalytic efficiencies against a range of P-1 substrates compared to their position 166 counterparts. This is probably because position 169 is at the bottom of the P-1 specificity subsite.

EXAMPLE 6

Substitution at Position 104

Tyr104 has been substituted with Ala, His, Leu, Met and Ser. The method used was a modification of the site directed mutagenesis method. According to the protocol of Figure 19, a primer (shaded in line 4) introduced a unique HindIII site and a frame shift mutation at codon 104. Restriction-purification for the unique HindIII site facilitated the isolation of the mutant sequence (line 4). Restriction-selection against this HindIII site using pimers in line 5 was used to obtain position 104 mutants.

The following triplets were used in the primers of Figure 19, line 5 for the 104 codon which substituted the following amino acids.

GCT	A	TTC	F
ATG	M	CCT	P
CTT	L	ACA	T
AGC	S	TGG	W
CAC	H	TAC	Y
CAA	Q	GTT	V
GAA	E	AGA	R
GGC	G	AAC	N
ATC	I	GAT	D
AAA	K	TGT	C

The substrates in Table XI were used to analyze the substrate specificity of these mutants. The results obtained fo H104 subtilisin are shown in Table XI.

TABLE XI

	kcat		Km		Kcat/Km	
Substrate	WT	H104	WT	H104	WT	H104
sAAPFpNA	50.0	22.0	1.4×10^{-4}	7.1×10^{-4}	3.6×10^{5}	3.1×10^{4}
sAAPApNA	3.2	2.0	2.3×10^{-4}	1.9×10^{-3}	1.4×10^{4}	1×10^{3}
sFAPFpNA	26.0	38.0	1.8×10^{-4}	4.1×10^{-4}	1.5×10^{5}	9.1×10^{4}
sFAPApNA	0.32	2.4	7.3×10^{-5}	1.5×10^{-4}	4.4×10^{3}	1.6×10^{4}

From these data it is clear that the substitution of His for Tyr at position 104 produces an enzyme which is more efficient (higher kcat/Km) when Phe is at the P-4 substrate position than when Ala is at the P-4 substrate position.

EXAMPLE 7

Substitution of Ala152

Ala152 has been substituted by Gly and Ser to determine the effect of such substitutions on substrate specificity.

The wild type DNA sequence was mutated by the V152/P153 primer (Figure 20, line 4) using the above restriction-purification approach for the new KpnI site. Other mutant primers (shaded sequences Figure 20; S152, line 5 and G152, line 6) mutated the new KpnI site away and such mutants were isolated using the restriction-selection procedure as described above for loss of the KpnI site.

The results of these substitutions for the above synthetic substrates containing the P-1 amino acids Phe, Leu and Ala are shown in Table XII.

TABLE XII

	P-1 Substrate (kcat/Kmx10^{-4})		
Position 152	Phe	Leu	Ala
Gly (G)	0.2	0.4	<0.04
Ala (wild type)	40.0	10.0	1.0
Ser (S)	1.0	0.5	0.2

These results indicate that, in contrast to positions 166 and 169, replacement of Ala152 with Ser or Gly causes a dramatic reduction in catalytic efficiencies

across all substrates tested. This suggests Ala152, at the top of the S-1 subsite, may be the optimal amino acid because Ser and Gly are homologous Ala substitutes.

EXAMPLE 8

Substitution at Position 156

Mutants containing the substitution of Ser and Gln for Glu156 have been constructed according to the overall method depicted in Figure 21. This method was designed to facilitate the construciton of multiple mutants at position 156 and 166 as will be described hereinafter. However, by regenerating the wild type Gly166, single mutations at Glu156 were obtained.

The plasmid pΔ166 is already depicted in line 2 of Figure 13. The synthetic oligonucleotides at the top right of Figure 21 represent the same DNA cassettes depicted in line 4 of Figure 13. The plasmid p166 in Figure 21 thus represents the mutant plasmids of Examples 3 and 4. In this particular example, p166 contains the wild type Gly166.

Construction of position 156 single mutants were prepared by ligation of the three fragments (1-3) indicated at the bottom of Figure 21. Fragment 3, containing the carboxy-terminal portion of the subtilisin gene including the wild type position 166 codon, was isolated as a 610 bp SacI-BamHI fragment. Fragment 1 contained the vector sequences, as well as the amino-terminal sequences of the subtilisin gene through codon 151. To produce fragment 1, a unique KpnI site at codon 152 was introduced into the wild type subtilisin sequence from pS4.5. Site-directed

mutagenesis in M13 employed a primer having the sequence 5'-TA-GTC-GTT-GCG-GTA-CCC-GGT-AAC-GAA-3' to produce the mutation. Enrichment for the mutant sequence was accomplished by restriction with KpnI, purification and self ligation. The mutant sequence containing the KpnI site was confirmed by direct plasmid sequencing to give pV152. pV152 (~1 μg) was digested with KpnI and treated with 2 units of DNA polymerase I large fragment (Klenow fragment from Boeringer-Mannheim) plus 50 μM deoxynucleotide triphosphates at 37°C for 30 min. This created a blunt end that terminated with codon 151. The DNA was extracted with 1:1 volumes phenol and $CHCl_3$ and DNA in the aqueous phase was precipitated by addition of 0.1 volumes 5M ammonium acetate and two volumes ethanol. After centrifugation and washing the DNA pellet with 70% ethanol, the DNA was lyophilized. DNA was digested with BamHI and the 4.6kb piece (fragment 1) was purified by acrylamide gel electrophoresis followed by electroelution. Fragment 2 was a duplex synthetic DNA cassette which when ligated with fragments 1 and 3 properly restored the coding sequence except at codon 156. The top strand was synthesized to contain a glutamine codon, and the complementary bottom strand coded for serine at 156. Ligation of heterophosphorylated cassettes leads to a large and favorable bias for the phosphorylated over the non-phosphorylated oligonucleotide sequence in the final segrated plasmid product. Therefore, to obtain Q156 the top strand was phosphorylated, and annealed to the non-phosphorylated bottom strand prior to ligation. Similarly, to obtain S156 the bottom strand was phosphorylated and annealed to the non-phosphorylated top strand. Mutant sequences were isolated after ligation and transformation, and were confirmed by restriction analysis and DNA sequencing

as before. To express variant subtilisins, plasmids were transformed into a subtilisin-neutral protease deletion mutant of B. subtilis, BG2036, as previously described. Cultures were fermented in shake flasks for 24 h at 37°C in LB media containing 12.5 mg/mL chloramphenicol and subtilisin was purified from culture supernatants as described. Purity of subtilisin was greater than 95% as judged by SDS PAGE.

These mutant plasmids designated pS156 and pQ156 and mutant subtilisins designated S156 and Q156 were analyzed with the above synthetic substrates where P-1 comprised the amino acids Glu, Gln, Met and Lys. The results of this analyses are presented in Example 9.

EXAMPLE 9

Multiple Mutants With Altered Substrate Specificity - Substitution at Positions 156 and 166

Single substitutions of position 166 are described in Examples 3 and 4. Example 8 describes single substitutions at position 156 as well as the protocol of Figure 21 whereby various double mutants comprising the substitution of various amino acids at positions 156 and 166 can be made. This example describes the construction and substrate specificity of subtilisin containing substitutions at position 156 and 166 and summarizes some of the data for single and double mutants at positions 156 and 166 with various substrates.

K166 is a common replacement amino acid in the 156/166 mutants described herein. The replacement of Lys for

Gly166 was achieved by using the synthetic DNA cassette at the top right of Figure 21 which contained the triplet AAA for NNN. This produced fragment 2 with Lys substituting for Gly166.

The 156 substituents were Gln and Ser. The Gln and Ser substitutions at Gly156 are contained within fragment 3 (bottom right Figure 21).

The multiple mutants were produced by combining fragments 1, 2 and 3 as described in Example 8. The mutants Q156/K166 and S156/K166 were selectively generated by differential phosphorylation as described. Alternatively, the double 156/166 mutants, c.f. Q156/K166 and S156/K166, were prepared by ligation of the 4.6kb SacI-BamHI fragment from the relevant p156 plasmid containing the 0.6kb SacI-BamHI fragment from the relevant p166 plasmid.

These mutants, the single mutant K166, and the S156 and Q156 mutants of Example 8 were analyzed for substitute specificity against synthetic polypeptides containing Phe or Glu as the P-1 substrate residue. The results are presented in Table XIII.

TABLE XIII

Enzymes Compared[b]	Substrate P-1 Residue	kcat	Km	kcat/Km	kcat/Km (mutant) / kcat/Km(wt)
Glu156/Gly166 (WT)	Phe	50.00	1.4×10^{-4}	3.6×10^{5}	(1)
	Glu	0.54	3.4×10^{-2}	1.6×10^{1}	(1)
K166	Phe	20.00	4.0×10^{-5}	5.2×10^{5}	1.4
	Glu	0.70	5.6×10^{-5}	1.2×10^{4}	750
Q156/K166	Phe	30.00	1.9×10^{-5}	1.6×10^{6}	4.4
	Glu	1.60	3.1×10^{-5}	5.0×10^{4}	3100
S156/K166	Phe	30.00	1.8×10^{-5}	1.6×10^{6}	4.4
	Glu	0.60	3.9×10^{-5}	1.6×10^{4}	1000
S156	Phe	34.00	4.7×10^{-5}	7.3×10^{5}	2.0
	Glu	0.40	1.8×10^{-3}	1.1×10^{2}	6.9
E156	Phe	48.00	4.5×10^{-5}	1.1×10^{6}	3.1
	Glu	0.90	3.3×10^{-3}	2.7×10^{2}	17

As can be seen in Table XIV, either of these single mutations improve enzyme performance upon substrates with glutamate at the P-1 enzyme binding site. When these single mutations were combined, the resulting multiple enzyme mutants are better than either parent. These single or multiple mutations also alter the relative pH activity profiles of the enzymes as shown in Figure 23.

To isolate the contribution of electrostatics to substrate specificity from other chemical binding forces, these various single and double mutants were analyzed for their ability to bind and cleave synthetic substrates containing Glu, Gln, Met and Lys as the P-1 substrate amino acid. This permitted comparisons between side-chains that were more sterically similar but differed in charge (e.g., Glu versus Gln, Lys versus Met). Similarly, mutant enzymes were assayed against homologous P-1 substrates that were most sterically similar but differed in charge (Table XIV).

TABLE XIV

Kinetics of Position 156/166 Subtilisins
Determined for Different P1 Substrates

Enzyme Position (a)		Net Charge (b)	P-1 Substrate log kcat/Km (log 1/Km) (c)			
			Glu	Gln	Met	Lys
156	166					
Glu	Asp	-2	n.d.	3.02 (2.56)	3.93 (2.74)	4.23 (3.00)
Glu	Glu	-2	n.d.	3.06 (2.91)	3.86 (3.28)	4.48 (3.69)
Glu	Asn	-1	1.62 (2.22)	3.85 (3.14)	4.99 (3.85)	4.15 (2.88)
Glu	Gln	-1	1.20 (2.12)	4.36 (3.64)	5.43 (4.36)	4.10 (3.15)
Gln	Asp	-1	1.30 (1.79)	3.40 (3.08)	4.94 (3.87)	4.41 (3.22)
Ser	Asp	-1	1.23 (2.13)	3.41 (3.09)	4.67 (3.68)	4.24 (3.07)
Glu	Met	-1	1.20 (2.30)	3.89 (3.19)	5.64 (4.83)	4.70 (3.89)
Glu	Ala	-1	n.d.	4.34 (3.55)	5.65 (4.46)	4.90 (3.24)
Glu	Gly(wt)	-1	1.20 (1.47)	3.85 (3.35)	5.07 (3.97)	4.60 (3.13)
Gln	Gly	0	2.42 (2.48)	4.53 (3.81)	5.77 (4.61)	3.76 (2.82)
Ser	Gly	0	2.31 (2.73)	4.09 (3.68)	5.61 (4.55)	3.46 (2.74)
Gln	Asn	0	2.04 (2.72)	4.51 (3.76)	5.79 (4.66)	3.75 (2.74)
Ser	Asn	0	1.91 (2.78)	4.57 (3.82)	5.72 (4.64)	3.68 (2.80)
Glu	Arg	0	2.91 (3.30)	4.26 (3.50)	5.32 (4.22)	3.19 (2.80)
Glu	Lys	0	4.09 (4.25)	4.70 (3.88)	6.15 (4.45)	4.23 (2.93)
Gln	Lys	+1	4.70 (4.50)	4.64 (3.68)	5.97 (4.68)	3.23 (2.75)
Ser	Lys	+1	4.21 (4.40)	4.84 (3.94)	6.16 (4.90)	3.73 (2.84)
Maximum difference: log kcat/Km (log 1/Km) (d)			3.5 (3.0)	1.8 (1.4)	2.3 (2.2)	-1.3 (-1.0)

Footnotes to Table XIV:

(a) B. subtilis, BG 2036, expressing indicated variant subtilisin were fermented and enzymes purified as previously described (Estell, et al. (1985) J. Biol. Chem. 260, 6518-6521). Wild type subtilisin is indicated (wt) containing Glu156 and Gly166.

(b) Net charge in the P-1 binding site is defined as the sum of charges from positions 156 and 166 at pH 8.6.

(c) Values for kcat(s^{-1}) and Km(M) were measured in 0.1M Tris pH 8.6 at 25°C as previously described against P-1 substrates having the form succinyl-L-AlaL-AlaL-ProL-[X]-p-nitroanilide, where X is the indicated P-1 amino acid. Values for log 1/Km are shown inside parentheses. All errors in determination of kcat/Km and 1/Km are below 5%.

(d) Because values for Glu156/Asp166(D166) are too small to determine accurately, the maximum difference taken for GluP-1 substrate is limited to a charge range of +1 to -1 charge change.

n.d. = not determined

The kcat/Km ratios shown are the second order rate constants for the conversion of substrate to product, and represent the catalytic efficiency of the enzyme. These ratios are presented in logarithmic form to scale the data, and because log kcat/Km is proportional to the lowering of transition-state activation energy (ΔG_T). Mutations at position 156 and 166 produce changes in catalytic efficiency toward Glu, Gln, Met and Lys P-1 substrates of 3100, 60, 200 and 20 fold, respectively. Making the P-1 binding-site more positively charged [e.g., compare Gln156/Lys166 (Q156/K166) versus Glu156/Met166 (Glu156/M166)] dramatically increased kcat/Km toward the Glu P-1 substrate (up to 3100 fold), and decreased the catalytic efficiency toward the Lys P-1 substrate (up to 10 fold). In addition, the results show that the catalytic efficiency of wild type enzyme can be

greatly improved toward any of the four P-1 substrates by mutagenesis of the P-1 binding site.

The changes in kcat/Km are caused predominantly by changes in 1/Km. Because 1/Km is approximately equal to 1/Ks, the enzyme-substrate association constant, the mutations primarily cause a change in substrate binding. These mutations produce smaller effects on kcat that run parallel to the effects on 1/Km. The changes in kcat suggest either an alteration in binding in the P-1 binding site in going from the Michaelis-complex E·S) to the transition-state complex (E-S≠) as previously proposed (Robertus, J.D., et al. (1972) Biochemistry 11, 2439-2449; Robertus, J.D., et al. (1972) Biochemistry 11, 4293-4303), or change in the position of the scissile peptide bond over the catalytic serine in the E·S complex.

Changes in substrate preference that arise from changes in the net charge in the P-1 binding site show trends that are best accounted for by electrostatic effects (Figure 28). As the P-1 binding cleft becomes more positively charged, the average catalytic efficiency increases much more for the Glu P-1 substrate than for its neutral and isosteric P-1 homolog, Gln (Figure 28A). Furthermore, at the positive extreme both substrates have nearly identical catalytic efficiencies.

In contrast, as the P-1 site becomes more positively charged the catalytic efficiency toward the Lys P-1 substrate decreases, and diverges sharply from its neutral and isosteric homolog, Met (Figure 28B). The similar and parallel upward trend seen with increasing positive charge for the Met and Glu P-1 substrates probably results from the fact that all the substrates

are succinylated on their amino-terminal end, and thus carry a formal negative charge.

The trends observed in log kcat/Km are dominated by changes in the Km term (Figures 28C and 28D). As the pocket becomes more positively charged, the log 1/Km values converge for Glu and Gln P-1 substrates (Figure 28C), and diverge for Lys and Met P-1 substrates (Figure 28D). Although less pronounced effects are seen in log kcat, the effects of P-1 charge on log kcat parallel those seen in log 1/Km and become larger as the P-1 pocket becomes more positively charged. This may result from the fact that the transition-state is a tetrahedral anion, and a net positive charge in the enzyme may serve to provide some added stabilization to the transition-state.

The effect of the change in P-1 binding-site charge on substrate preference can be estimated from the differences in slopes between the charged and neutral isosteric P-1 substrates (Figure 28B). The average change in substrate preference (Δlog kcat/Km) between charged and neutral isosteric substrates increases roughly 10-fold as the complementary charge or the enzyme increases (Table XV). When comparing Glu versus Lys, this difference is 100-fold and the change in substrate preference appears predominantly in the Km term.

TABLE XV

Differential Effect on Binding Site Charge on log kcat/Km or (log 1/Km) for P-1 Substrates that Differ in Charge (a)

Change in P-1 Binding Site Charge (b)	Δlog kcat/Km GluGln	MetLys	(Δlog 1/Km) GluLys
-2 to -1	n.d.	1.2 (1.2)	n.d.
-1 to 0	0.7 (0.6)	1.3 (0.8)	2.1 (1.4)
0 to +1	1.5 (1.3)	0.5 (0.3)	2.0 (1.5)
Avg. change in log kcat/K_m or (log 1/Km) per unit charge change	1.1 (1.0)	1.0 (0.8)	2.1 (1.5)

(a) The difference in the slopes of curves were taken between the P-1 substrates over the charge interval given for log (kcat/Km) (Figure 28A, B) and (log 1/Km) (Figure 28C, D). Values represent the differential effect a charge change has in distinguishing the substrates that are compared.

(b) Charge in P-1 binding site is defined as the sum of charges from positions 156 and 166.

The free energy of electrostatic interactions in the structure and energetics of salt-bridge formation depends on the distance between the charges and the microscopic dielectric of the media. To dissect these structural and microenvironmental effects, the energies involved in specific salt-bridges were evaluated. In addition to the possible salt-bridges shown (Figures 29A and 29B), reasonable salt-bridges can be built between a Lys P-1 substrate and Asp at position 166, and between a Glu P-1 substrate and a Lys at position 166 (not shown). Although only one of these structures is confirmed by X-ray crystalography (Poulos, T.L., et al. (1976) J. Mol. Biol. 257 1097-1103), all models have favorable torsion angles (Sielecki, A.R., et al. (1979) J. Mol. Biol. 134, 781-804), and do not introduce unfavorable van der Waals contacts.

The change in charged P-1 substrate preference brought about by formation of the model salt-bridges above are shown in Table XVI.

TABLE XVI

Effect of Salt Bridge Formation Between Enzyme and Substrate on P1 Substrate Preference[a]

Enzymes Compared[b] 1	Enzymes Compared[b] 2	Enzyme Position Changed	P-1 Substrates Compared	Substrate Preference[d] Δlog (kcat/Km) 1	Substrate Preference[d] Δlog (kcat/Km) 2	Change in Substrate Preference ΔΔlog (kcat/Km) (1-2)
Glu156/Asp166	Gln156/Asp166	156	LysMet	+0.30	-0.53	0.83
Glu156/Asn166	Gln156/Asn166	156	LysMet	-0.84	-2.04	1.20
Glu156/Gly166	Gln156/Gly166	156	LysMet	-0.47	-2.10	1.63
Glu156/Lsy-166	Gln156/Lys166	156	LysMet	-1.92	-2.74	0.82
				Ave ΔΔlog (kcat/Km)		1.10 ± 0.3
Glu156/Asp166	Glu156/Asn166	166	LysMet	+0.30	-0.84	1.14
Glu156/Glu166	Glu156/Glu166	166	LysMet	+0.62	-1.33	1.95
Gln156/Asp166	Gln156/Asn166	166	LysMet	-0.53	-2.04	1.51
Ser156/Asp166	Ser156/Asn166	166	LysMet	-0.43	-2.04	1.61
Glu156/Lys166	Glu156/Met166	166	GluGln	-0.63	-2.69	2/06
				Ave ΔΔlog (kcat/Km)		1.70 ± 0.3

Footnotes to Table XVI:

(a) Molecular modeling shows it is possible to form a salt bridge between the indicated charged P-1 substrate and a complementary charge in the P-1 binding site of the enzyme at the indicated position changed.

(b) Enzymes compared have sterically similar amino acid substitutions that differ in charge at the indicated position.

(c) The P-1 substrates compared are structurally similar but differ in charge. The charged P-1 substrate is complementary to the charge change at the position indicated between enzymes 1 and 2.

(d) Date from Table XIV was used to compute the difference in log (kcat/Km) between the charged and the non-charged P-1 substrate (i.e., the substrate preference). The substrate preference is shown separately for enzyme 1 and 2.

(e) The difference in substrate preference between enzyme 1 (more highly charged) and enzyme 2 (more neutral) represents the rate change accompanying the electrostatic interaction.

The difference between catalytic efficiencies (i.e., Δlog kcat/Km) for the charged and neutral P-1 substrates (e.g., Lys minus Met or Glu minus Gln) give the substrate preference for each enzyme. The change in substrate preference (ΔΔlog kcat/Km) between the charged and more neutral enzyme homologs (e.g., Glu156/Gly166 minus Gln156(Q156)/Gly166) reflects the change in catalytic efficiency that may be attributed solely to electrostatic effects.

These results show that the average change in substrate preference is considerably greater when electrostatic substitutions are produced at position 166 (50-fold in kcat/Km) versus position 156 (12-fold in kcat/Km). From these ΔΔlog kcat/Km values, an average change in transition-state stabilization energy can be calculated of -1.5 and -2.4 kcal/mol for

substitutions at positions 156 and 166, respectively. This should represent the stabilization energy contributed from a favorable electrostatic interaction for the binding of free enzyme and substrate to form the transition-state complex.

EXAMPLE 10

Substitutions at Position 217

Tyr217 has been substituted by all other 19 amino acids. Cassette mutagenesis as described in EPO publication No. 0130756 was used according to the protocol of Figure 22. The EcoRV restriction site was used for restriction-purification of pΔ217.

Since this position is involved in substrate binding, mutations here effect kinetic parameters of the enzyme. An example is the substitution of Leu for Tyr at position 217. For the substrate sAAPFpNa, this mutant has a kcat of 277 5' and a Km of 4.7×10^{-4} with a kcat/Km ratio of 6×10^{5}. This represents a 5.5-fold increase in kcat with a 3-fold increase in Km over the wild type enzyme.

In addition, replacement of Tyr217 by Lys, Arg, Phe or Leu results in mutant enzymes which are more stable at pHs of about 9-11 than the WT enzyme. Conversely, replacement of Tyr217 by Asp, Glu, Gly or Pro results in enzymes which are less stable at pHs of about 9-11 than the WT enzyme.

EXAMPLE 11

Multiple Mutants Having
Altered Thermal Stability

B. amyloliquefacien subtilisin does not contain any cysteine residues. Thus, any attempt to produce thermal stability by Cys cross-linkage required the substitution of more than one amino acid in subtilisin with Cys. The following subtilisin residues were multiply substituted with cysteine:

Thr22/Ser87
Ser24/Ser87

Mutagenesis of Ser24 to Cys was carried out with a 5' phosphorylated oligonucleotide primer having the sequence

5'-pC-TAC-ACT-GGA-TG**C-AAT-GTT-AAA-G-3'.

(Asterisks show the location of mismatches and the underlined sequence shows the position of the altered Sau3A site.) The B. amyloliquefaciens subtilisin gene on a 1.5 kb EcoRI-BAMHI fragment from pS4.5 was cloned into M13mp11 and single stranded DNA was isolated. This template (M13mp11SUBT) was double primed with the 5' phosphorylated M13 universal sequencing primer and the mutagenesis primer. Adelman, et al. (1983) DNA 2, 183-193. The heteroduplex was transfected into competent JM101 cells and plaques were probed for the mutant sequence (Zoller, M.J., et al. (1982) Nucleic Acid Res. 10, 6487-6500; Wallace, et al. (1981) Nucleic Acid Res. 9, 3647-3656) using a tetramethylammonium chloride hybridization protocol (Wood, et al. (1985) Proc. Natl. Acad. Sci. USA 82, 1585-1588). The Ser87 to Cys mutation was prepared in

a similar fashion using a 5' phosphorylated primer having the sequence

5'-pGGC-GTT-GCG-CCA-*TGC-GCA-TCA-CT-3'.

(The asterisk indicates the position of the mismatch and the underlined sequence shows the position of a new MstI site.) The C24 and C87 mutations were obtained at a frequency of one and two percent, respectively. Mutant sequences were confirmed by dideoxy sequencing in M13.

Mutagenesis of Tyr21/Thr22 to A21/C22 was carried out with a 5' phosphorylated oligonucleotide primer having the sequence

5'-pAC-TCT-CAA-GGC-***GCT-**TGT-G*GC-TCA-AAT-GTT-3'.

(The asterisks show mismatches to the wild type sequence and the underlined sequence shows the position of an altered Sau3A site.) Manipulations for heteroduplex synthesis were identical to those described for C24. Because direct cloning of the heteroduplex DNA fragment can yield increased frequencies of mutagenesis, the EcoRI-BamHI subtilisin fragment was purified and ligated into pBS42. E. coli MM 294 cells were transformed with the ligation mixture and plasmid DNA was purified from isolated transformants. Plasmid DNA was screened for the loss of the Sau3A site at codon 23 that was eliminated by the mutagenesis primer. Two out of 16 plasmid preparations had lost the wild type Sau3A site. The mutant sequence was confirmed by dideoxy sequencing in M13.

Double mutants, C22/C87 and C24/C87, were constructed by ligating fragments sharing a common ClaI site that separated the single parent cystine codons. Specifically, the 500 bp EcoRI-ClaI fragment containing the 5' portion of the subtilisin gene (including codons 22 and 24) was ligated with the 4.7 kb ClaI-EcoRI fragment that contained the 3' portion of the subtilisin gene (including codon 87) plus pBS42 vector sequence. E. coli MM 294 was transformed with ligation mixtures and plasmid DNA was purified from individual transformants. Double-cysteine plasmid constructions were identified by restriction site markers originating from the parent cysteine mutants (i.e., C22 and C24, Sau3A minus; Cys87, MstI plus). Plasmids from E. coli were transformed into B. subtilis BG2036. The thermal stability of these mutants as compared to wild type subtilisin are presented in Figure 30 and Tables XVII and XVIII.

TABLE XVII

Effect of DTT on the Half-Time of Autolytic Inactivation of Wild-Type and Disulfide Mutants of Subtilisin*

Enzyme	$t_{\frac{1}{2}}$ -DDT	$t_{\frac{1}{2}}$ +DTT	-DTT/+DTT
	min		
Wild-type	95	85	1.1
C22/C87	44	25	1.8
C24/C87	92	62	1.5

(*) Purified enzymes were either treated or not treated with 25mM DTT and dialyzed with or without 10mM DTT in 2mM $CaCl_2$, 50mM Tris (pH 7.5) for 14 hr. at 4°C. Enzyme concentrations were adjusted to 80µl aliquots were quenched on ice and assayed for residual activity. Half-times for autolytic inactivation were determined from semi-log plots of $\log_{10}$ (residual activity) versus time. These plots were linear for over 90% of the inactivation.

TABLE XVIII

Effect of Mutations in Subtilisin on the Half-Time of Autolytic Inactivation at 58°C*

Enzyme	$t_{\frac{1}{2}}$ min
Wild-type	120
C22	22
C24	120
C87	104
C22/C87	43
C24/C87	115

(*) Half-times for autolytic inactivation were determined for wild-type and mutant subtilisins as described in the legend to Table III. Unpurified and non-reduced enzymes were used directly from B. subtilis culture supernatants.

The disulfides introduced into subtilisin did not improve the autolytic stability of the mutant enzymes when compared to the wild-type enzyme. However, the disulfide bonds did provide a margin of autolytic stability when compared to their corresponding reduced double-cysteine enzyme. Inspection of a highly refined x-ray structure of wild-type B. amyloliquefaciens subtilisin reveals a hydrogen bond between Thr22 and Ser87. Because cysteine is a poor hydrogen donor or acceptor (Paul, I.C. (1974) in Chemistry of the -SH Group (Patai, S., ed.) pp. 111-149, Wiley Interscience, New York) weakening of 22/87 hydrogen bond may explain why the C22 and C87 single-cysteine mutant proteins are less autolytically stable than either C24 or wild-type (Table XVIII). The fact that C22 is less autolytically stable than C87 may be the result of the Tyr21A mutation (Table XVIII). Indeed,

construction and analysis of Tyr21/C22 shows the mutant protein has an autolytic stability closer to that of C87. In summary, the C22 and C87 of single-cysteine mutations destabilize the protein toward autolysis, and disulfide bond formation increases the stability to a level less than or equal to that of wild-type enzyme.

EXAMPLE 12

Multiple Mutants Containing Substitutions at Position 222 and Position 166 or 169

Double mutants 166/222 and 169/222 were prepared by ligating together (1) the 2.3kb AcaII fragment from pS4.5 which contains the 5' portion of the subtilisin gene and vector sequences, (2) the 200bp AvaII fragment which contains the relevant 166 or 169 mutations from the respective 166 or 169 plasmids, and (3) the 2.2kb AvaII fragment which contains the relevant 222 mutation 3' and of the subtilisin genes and vector sequence from the respective p222 plasmid.

Although mutations at position 222 improve oxidation stability they also tend to increase the Km. An example is shown in Table XIX. In this case the A222 mutation was combined with the K166 mutation to give an enzyme with kcat and Km intermediate between the two parent enzymes.

TABLE XIX

	kcat	Km
WT	50	1.4×10^{-4}
A222	42	9.9×10^{-4}
K166	21	3.7×10^{-5}
K166/A222	29	2.0×10^{-4}

substrate sAAPFpNa

EXAMPLE 13

Multiple Mutants Containing Substitutions at Positions 50, 156, 166, 217 and Combinations Thereof

The double mutant S156/A169 was prepared by ligation of two fragments, each containing one of the relevant mutations. The plasmid pS156 was cut with XmaI and treated with S1 nuclease to create a blunt end at codon 167. After removal of the nuclease by phenol/chloroform extraction and ethanol precipitation, the DNA was digested with BamHI and the approximately 4kb fragment containing the vector plus the 5' portion of the subtilisin gene through codon 167 was purified.

The pA169 plasmid was digested with KpnI and treated with DNA polymerase Klenow fragment plus 50 μM dNTPs to create a blunt end codon at codon 168. The Klenow was removed by phenol/chloroform extraction and ethanol precipitation. The DNA was digested with BamHI and the 590bp fragment including codon 168 through the carboxy terminus of the subtilisin gene

was isolated. The two fragments were then ligated to give S156/A169.

Triple and quadruple mutants were prepared by ligating together (1) the 220bp PvuII/HaeII fragment containing the relevant 156, 166 and/or 169 mutations from the respective p156, p166 and/or p169 double of single mutant plasmid, (2) the 550bp HaeII/BamHI fragment containing the relevant 217 mutant from the respective p217 plasmid, and (3) the 3.9kb PvuII/BamHI fragment containing the F50 mutation and vector sequences.

The multiple mutant F50/S156/A169/L217, as well as B. amyloliquefaciens subtilisin, B. lichenformis subtilisin and the single mutant L217 were analyzed with the above synthetic polypeptides where the P-1 amino acid in the substrate was Lys, His, Ala, Gln, Tyr, Phe, Met and Leu. These results are shown in Figures 26 and 27.

These results show that the F50/S156/A169/L217 mutant has substrate specificity similar to that of the B. licheniformis enzyme and differs dramatically from the wild type enzyme. Although only data for the L217 mutant are shown, none of the single mutants (e.g., F50, S156 or A169) showed this effect. Although B. licheniformis differs in 88 residue positions from B. amyloliquefaciens, the combination of only these four mutations accounts for most of the differences in substrate specificity between the two enzymes.

EXAMPLE 14

Subtilisin Mutants Having Altered Alkaline Stability

A random mutagenesis technique was used to generate single and multiple mutations within the B.

amyloliquefaciens subtilisin gene. Such mutants were screened for altered alkaline stability. Clones having increased (positive) alkaline stability and decreased (negative) alkaline stability were isolated and sequenced to identify the mutations within the subtilisin gene. Among the positive clones, the mutants V107 and R213 were identified. These single mutants were subsequently combined to produce the mutant V107/R213.

One of the negative clones (V50) from the random mutagenesis experiments resulted in a marked decrease in alkaline stability. Another mutant (P50) was analyzed for alkaline stability to determine the effect of a different substitution at position 50. The F50 mutant was found to have a greater alkaline stability than wild type subtilisin and when combined with the double mutant V107/R213 resulted in a mutant having an alkaline stability which reflected the aggregate of the alkaline stabilities for each of the individual mutants.

The single mutant R204 and double mutant C204/R213 were identified by alkaline screening after random cassette mutagenesis over the region from position 197 to 228. The C204/R213 mutant was thereafter modified to produce mutants containing the individual mutations C204 and R213 to determine the contribution of each of the individual mutations. Cassette mutagenesis using pooled oligonucleotides to substitute all amino acids at position 204, was utilized to determine which substitution at position 204 would maximize the increase in alkaline stability. The mutation from Lys213 to Arg was maintained constant for each of these substitutions at position 204.

A. Construction of pB0180, an E. coli-B. subtilis Shuttle Plasmid

The 2.9 kb EcoRI-BamHI fragment from pBR327 (Covarrubias, L., et al. (1981) Gene 13, 25-35) was ligated to the 3.7kb EcoRI-BamHI fragment of pBD64 (Gryczan, T., et al. (1980) J. Bacteriol., 141, 246-253) to give the recombinant plasmid pB0153. The unique EcoRI recognition sequence in pBD64 was eliminated by digestion with EcoRI followed by treatment with Klenow and deoxynucleotide triphosphates (Maniatis, T., et al. (eds.) (1982) in Molecular Cloning, A Laboratory Manual, Cold Spring Harbor Laboratory, Cold Spring Harbor, N.Y.). Blunt end ligation and transformation yielded pB0154. The unique AvaI recognition sequence in pB0154 was eliminated in a similar manner to yield pB0171. pB0171 was digested with BamHI and PvuII and treated with Klenow and deoxynucleotide triphosphates to create blunt ends. The 6.4 kb fragment was purified, ligated and transformed into LE392 cells (Enquest, L.W., et al. (1977) J. Mol. Biol. 111, 97-120), to yield pB0172 which retains the unique BamHI site. To facilitate subcloning of subtilisin mutants, a unique and silent KpnI site starting at codon 166 was introduced into the subtilisin gene from pS4.5 (Wells, J.A., et al. (1983) Nucleic Acids Res., 11, 7911-7925) by site-directed mutagenesis. The KpnI+ plasmid was digested with EcoRI and treated with Klenow and deoxynucleotide triphosphates to create a blunt end. The Klenow was inactivated by heating for 20 min at 68°C, and the DNA was digested with BamHI. The 1.5 kb blunt EcoRI-BamHI fragment containing the entire subtilisin was ligated with the 5.8 kb NruI-BamHI from pB0172 to yield pB0180. The ligation of the blunt NruI end to the blunt EcoRI end recreated an EcoRI

site. Proceeding clockwise around pB0180 from the EcoRI site at the 5' end of the subtilisin gene is the unique BamHI site at the 3' end of the subtilisin gene, the chloramphenicol and neomycin resistance genes and UB110 gram positive replication origin derived from pBD64, the ampicillin resistance gene and gram negative replication origin derived from pBR327.

B. Construction of Random Mutagenesis Library

The 1.5 kb EcoRI-BamHI fragment containing the B. amyloliquefaciens subtilisin gene (Wells et al., 1983) from pB0180 was cloned into M13mp11 to give M13mp11 SUBT essentially as previously described (Wells, J.A., et al. (1986) J. Biol. Chem., 261,6564-6570). Deoxyuridine containing template DNA was prepared according to Kunkel (Kunkel, T.A. (1985) Proc. Natl. Acad. Sci. USA, 82 488-492). Uridine containing template DNA (Kunkel, 1985) was purified by CsCl density gradients (Maniatis, T. et al. (eds.) (1982) in Molecular Cloning, A Laboratory Manual, Cold Spring Harbor Laboratory, Cold Spring Harbor, N.Y.). A primer (AvaI$^-$) having the sequence

5'GAAAAAAGACCC*TAGCGTCGCTTA

ending at codon -11, was used to alter the unique AvaI recognition sequence within the subtilisin gene. (The asterisk denotes the mismatches from the wild-type sequence and underlined is the altered AvaI site.)

The 5' phosphorylated AvaI primer (~320 pmol) and ~40 pmol (~120µg) of uridine containing M13mp11 SUBT template in 1.88 ml of 53 mM NaCl, 7.4 mM MgCl2 and 7.4 mM Tris.HCl (pH 7.5) were annealed by heating to

90°C for 2 min. and cooling 15 min at 24°C (Fig. 31). Primer extension at 24°C was initiated by addition of 100µL containing 1 mM in all four deoxynucleotide triphosphates, and 20µl Klenow fragment (5 units/l). The extension reaction was stopped every 15 seconds over ten min by addition of 10µl 0.25 M EDTA (pH 8) to 50µl aliquots of the reaction mixture. Samples were pooled, phenol chlorophorm extracted and DNA was precipitated twice by addition of 2.5 vol 100% ethanol, and washed twice with 70% ethanol. The pellet was dried, and redissolved in 0.4 ml 1 mM EDTA, 10 mM Tris (pH 8).

Misincorporation of α-thiodeoxynucleotides onto the 3' ends of the pool of randomly terminated template was carried out by incubating four 0.2 ml solutions each containing one-fourth of the randomly terminated template mixture (~20µg), 0.25 mM of a given α-thiodeoxynucleotide triphosphate, 100 units AMV polymerase, 50 mM KCL, 10 mM $MgCl_2$, 0.4 mM dithiothreitol, and 50 mM Tris (pH 8.3) (Champoux, J.J. (1984) Genetics, 2, 454-464). After incubation at 37°C for 90 minutes, misincorporation reactions were sealed by incubation for five minutes at 37°C with 50 mM all four deoxynucleotide triphosphates (pH 8), and 50 units AMV polymerase. Reactions were stopped by addition of 25 mM EDTA (final), and heated at 68°C for ten min to inactivate AMV polymerase. After ethanol precipitation and resuspension, synthesis of closed circular heteroduplexes was carried out for two days at 14°C under the same conditions used for the timed extension reactions above, except the reactions also contained 1000 units T4 DNA ligase, 0.5 mM ATP and 1 mM β-mercaptoethanol. Simultaneous restriction of each heteroduplex pool with KpnI, BamHI, and EcoRI confirmed that the

extension reactions were nearly quantitative. Heteroduplex DNA in each reaction mixture was methylated by incubation with 80μM S-adenosylmethionine and 150 units dam methylase for 1 hour at 37°C. Methylation reactions were stopped by heating at 68°C for 15 min.

One-half of each of the four methylated heteroduplex reactions were transformed into 2.5 ml competent E. coli JM101 (Messing, J. (1979) Recombinant DNA Tech. Bull., 2, 43-48). The number of independent transformants from each of the four transformations ranged from 0.4-2.0 x 10^5. After growing out phage pools, RF DNA from each of the four transformations was isolated and purified by centrifugation through CsCl density gradients. Approximately 2μg of RF DNA from each of the four pools was digested with EcoRI, BamHI and AvaI. The 1.5 kb EcoRI-BamHI fragment (i.e., AvaI resistant) was purified on low gel temperature agarose and ligated into the 5.5 kb EcoRI-BamHI vector fragment of pB0180. The total number of independent transformants from each α-thiodeoxynucleotide misincorporation plasmid library ranged from 1.2-2.4 x 10^4. The pool of plasmids from each of the four transformations was grown out in 200 ml LB media containing 12.5μg/ml cmp and plasmid DNA was purified by centrifugation through CsCl density gradients.

C. Expression and Screening of Subtilisin Point Mutants

Plasmid DNA from each of the four misincorporation pools was transformed (Anagnostopoulos, C., et al. (1967), J. Bacteriol., 81, 741-746) into BG2036. For each transformation, 5μg of DNA produced approximately

2.5×10^5 independent BG2036 transformants, and liquid culture aliquots from the four libraries were stored in 10% glycerol at 70°C. Thawed aliquots of frozen cultures were plated on LB/5μg/ml cmp/1.6% skim milk plates (Wells, J.A., et al. (1983) Nucleic Acids Res., 11, 7911-7925), and fresh colonies were arrayed onto 96-well microtiter plates containing 150 l per well LB media plus 12.5μg/ml cmp. After 1 h at room temperature, a replica was stamped (using a matched 96 prong stamp) onto a 132 mm BA 85 nitrocellulose filter (Schleicher and Scheull) which was layered on a 140 mm diameter LB/cmp/skim milk plate. Cells were grown about 16 h at 30°C until halos of proteolysis were roughly 5-7 mm in diameter and filters were transferred directly to a freshly prepared agar plate at 37°C containing only 1.6% skim milk and 50 mM sodium phosphate pH 11.5. Filters were incubated on plates for 3-6 h at 37°C to produce halos of about 5 mm for wild-type subtilisin and were discarded. The plates were stained for 10 min at 24°C with Coomassie blue solution (0.25% Coomassie blue (R-250) 25% ethanol) and destained with 25% ethanol, 10% acetic acid for 20 min. Zones of proteolysis appeared as blue halos on a white background on the underside of the plate and were compared to the original growth plate that was similarly stained and destained as a control. Clones were considered positive that produced proportionately larger zones of proteolysis on the high pH plates relative to the original growth plate. Negative clones gave smaller halos under alkaline conditions. Positive and negative clones were restreaked to colony purify and screened again in triplicate to confirm alkaline pH results.

D. Identification and Analysis of Mutant Subtilisins

Plasmid DNA from 5 ml overnight cultures of more alkaline active B.subtilis clones was prepared according to Birnboim and Doly (Birnboim, H.C., et al. (1979) Nucleic Acid Res. 7, 1513) except that incubation with 2 mg/ml lysozyme proceeded for 5 min at 37°C to ensure cell lysis and an additional phenol/$CHCl_3$ extraction was employed to remove contaminants. The 1.5 kb EcoRI-BamHI fragment containing the subtilisin gene was ligated into M13mp11 and template DNA was prepared for DNA sequencing (Messing, J., et al. (1982) Gene, 19 269-276). Three DNA sequencing primers ending at codon 26, +95, and +155 were synthesized to match the subtilisin coding sequence. For preliminary sequence identification a single track of DNA sequence, corresponding to the dNTPaS misincorporation library from which the mutant came, was applied over the entire mature protein coding sequence (i.e., a single dideoxyguanosine sequence track was applied to identify a mutant from the dGTPas library). A complete four track of DNA sequence was performed 200 bp over the site of mutagenesis to confirm and identify the mutant sequence (Sanger, F., et al., (1980) J. Mol. Biol., 143, 161-178). Confirmed positive and negative bacilli clones were cultured in LB media containing 12.5µg/mL cmp and purified from culture supernatants as previously described (Estell, D.A., et al. (1985) J. Biol. Chem., 260, 6518-6521). Enzymes were greater than 98% pure as analyzed by SDS-polyacrylamide gel electrophoresis (Laemmli, U.K. (1970), Nature, 227, 680-685), and protein concentrations were calculated from the absorbance at 280 nm, $\varepsilon_{280}^{0.1\%} = 1.17$ (Maturbara, H., et al. (1965), J. Biol. Chem, 240, 1125-1130).

Enzyme activity was measured with 200μg/mL succinyl-L-AlaL-AlaL-ProL-Phep-nitroanilide (Sigma) in 0.1M Tris pH 8.6 or 0.1 M CAPS pH 10.8 at 25°C. Specific activity (μ moles product/min-mg) was calculated from the change in absorbance at 410 nm from production of p-nitroaniline with time per mg of enzyme (E410 = 8,480 M-1cm-1; Del Mar, E.G., et al. (1979), Anal. Biochem., 99, 316-320). Alkaline autolytic stability studies were performed on purified enzymes (200μg/mL) in 0.1 M potassium phosphate (pH 12.0) at 37°C. At various times aliquots were assayed for residual enzyme activity (Wells, J.A., et al. (1986) J. Biol. Chem., 261, 6564-6570).

E. Results

1. Optimization and analysis of mutagenesis frequency

A set of primer-template molecules that were randomly 3'-terminated over the subtilisin gene (Fig. 31) was produced by variable extension from a fixed 5'-primer (The primer mutated a unique AvaI site at codon 11 in the subtilisin gene). This was achieved by stopping polymerase reactions with EDTA after various times of extension. The extent and distribution of duplex formation over the 1 kb subtilisin gene fragment was assessed by multiple restriction digestion (not shown). For example, production of new HinfI fragments identified when polymerase extension had proceeded past Ile110, Leu233, and Asp259 in the subtilisin gene.

Misincorporation of each dNTPαs at randomly terminated 3' ends by AMV reverse transcriptase (Zakour, R.A., et al. (1982), Nature, 295, 708-710; Zakour, R.A., et al. (1984), Nucleic Acids Res., 12, 6615-6628) used

conditions previously described (Champoux, J.J., (1984), Genetics, 2, 454-464). The efficiency of each misincorporation reaction was estimated to be greater than 80% by the addition of each dNTPαs to the AvaI restriction primer, and analysis by polyacrylamide gel electrophoresis. Misincorporations were sealed by polymerization with all four dNTP's and closed circular DNA was produced by reaction with DNA ligase.

Several manipulations were employed to maximize the yield of the mutant sequences in the heteroduplex. These included the use of a deoxyuridine containing template (Kunkel, T.A. (1985), Proc. Natl. Acad. Sci. USA, 82 488-492; Pukkila, P.J. et al. (1983), Genetics, 104, 571-582), in vitro methylation of the mutagenic strand (Kramer, W. et al. (1982) Nucleic Acids Res., 10 6475-6485), and the use of AvaI restriction-selection against the wild-type template strand which contained a unique AvaI site. The separate contribution of each of these enrichment procedures to the final mutagenesis frequency was not determined, except that prior to AvaI restriction-selection roughly one-third of the segregated clones in each of the four pools still retained a wild-type AvaI site within the subtilisin gene. After AvaI restriction-selection greater than 98% of the plasmids lacked the wild-type AvaI site.

The 1.5 kb EcoRI-BamHI subtilisin gene fragment that was resistant to AvaI restriction digestion, from each of the four CsCl purified M13 RF pools was isolated on low melting agarose. The fragment was ligated in situ from the agarose with a similarly cut E. coli-B. subtilis shuttle vector, pB0180, and transformed directly into E coli LE392. Such direct ligation and transformation of DNA isolated from agarose avoided

loses and allowed large numbers of recombinants to be obtained (>100,000 per µg equivalent of input M13 pool).

The frequency of mutagenesis for each of the four dNTPαs misincorporation reactions was estimated from the frequency that unique restriction sites were eliminated (Table XX). The unique restriction sites chosen for this analysis, ClaI, PvuII, and KpnI, were distributed over the subtilisin gene starting at codons 35, 104, and 166, respectively. As a control, the mutagenesis frequency was determined at the PstI site located in the β lactamase gene which was outside the window of mutagenesis. Because the absolute mutagenesis frequency was close to the percentage of undigested plasmid DNA, two rounds of restriction-selection were necessary to reduce the background of surviving uncut wild-type plasmid DNA below the mutant plasmid (Table XX). The background of surviving plasmid from wild-type DNA probably represents the sum total of spontaneous mutations, uncut wild-type plasmid, plus the efficiency with which linear DNA can transform E. coli. Subtracting the frequency for unmutagenized DNA (background) from the frequency for mutant DNA, and normalizing for the window of mutagenesis sampled by a given restriction analysis (4-6 bp) provides an estimate of the mutagenesis efficiency over the entire coding sequence (~1000 bp).

TABLE XX

α-thiol dNTP misincorporated[b]	Restriction Site Selection	% resistant clones[c] 1st round	2nd round	Total	% resistant clones over Background[d]	% mutants per 1000bp[e]
None	PstI	0.32	0.7	0.002	0	-
G	PstI	0.33	1.0	0.003	0.001	0.2
T	PstI	0.32	<0.5	<0.002	0	0
C	PstI	0.43	3.0	0.013	0.011	3
None	ClaI	0.28	5	0.014	0	-
G	ClaI	2.26	85	1.92	1.91	380
T	ClaI	0.48	31	0.15	0.14	35
C	ClaI	0.55	15	0.08	0.066	17
None	PvuII	0.08	29	0.023	0	-
G	PvuII	0.41	90	0.37	0.35	88
T	PvuII	0.10	67	0.067	0.044	9
C	PvuII	0.76	53	0.40	0.38	95
None	KpnI	0.41	3	0.012	0	-
G	KpnI	0.98	35	0.34	0.33	83
T	KpnI	0.36	15	0.054	0.042	8
C	KpnI	1.47	26	0.38	0.37	93

(a) Mutagenesis frequency is estimated from the frequency for obtaining mutations that alter unique restriction sites within the mutagenized subtilisin gene (i.e., ClaI, PvuII, or KpnI) compared to mutation frequencies of the PstI site, that is outside the window of mutagenesis.

(b) Plasmid DNA was from wild-type (none) or mutagenized by dNTPαs misincorporation as described.

(c) Percentage of resistant clones was calculated from the fraction of clones obtained after three fold or greater over-digestion of the plasmid with the indicated restriction enzyme compared to a

non-digested control. Restriction-resistant plasmid DNA from the first round was subjected to a second round of restriction-selection. The total represents the product of the fractions of resistant clones obtained from both rounds of selection and gives percentage of restriction-site mutant clones in the original starting pool. Frequencies were derived from counting at least 20 colonies and usually greater than 100.

(d) Percent resistant clones was calculated by subtracting the percentage of restriction-resistant clones obtained for wild-type DNA (i.e., none) from that obtained for mutant DNA.

(e) This extrapolates from the frequency of mutation over each restriction site to the entire subtilisin gene (~1 kb). This has been normalized to the number of possible bases (4-6 bp) within each restriction site that can be mutagenized by a given misincorporation event.

From this analysis, the average percentage of subtilisin genes containing mutations that result from dGTPαs, dCTPαs, or dTTPαs misincorporation was estimated to be 90, 70, and 20 percent, respectively. These high mutagenesis frequencies were generally quite variable depending upon the dNTPαs and misincorporation efficiencies at this site. Misincorporation efficiency has been reported to be both dependent on the kind of mismatch, and the context of primer (Champoux, J.J., (1984); Skinner, J.A., et al. (1986) Nucleic Acids Res., 14, 6945-6964). Biased misincorporation efficiency of dGTPαs and dCTPαs over dTTPαs has been previously observed (Shortle, D., et al. (1985), Genetics, 110, 539-555). Unlike the dGTPαs, dCTPαs, and dTTPαs libraries the efficiency of mutagenesis for the dATPαs

misincorporation library could not be accurately assessed because 90% of the restriction-resistant plasmids analyzed simply lacked the subtilisin gene insert. This problem probably arose from self-ligation of the vector when the dATPαs mutagenized subtilisin gene was subcloned from M13 into pB0180. Correcting for the vector background, we estimate the mutagenesis frequency around 20 percent in the dATPαs misincorporation library. In a separate experiment (not shown), the mutagenesis efficiencies for dGTPαs and dTTPαs misincorporation were estimated to be around 50 and 30 percent, respectively, based on the frequency of reversion of an inactivating mutation at codon 169.

The location and identity of each mutation was determined by a single track of DNA sequencing corresponding to the misincorporated αthiodeoxynucleotide over the entire gene followed by a complete four track of DNA sequencing focused over the site of mutation. Of 14 mutants identified, the distribution was similar to that reported by Shortle and Lin (1985) except we did not observe nucleotide insertion or deletion mutations. The proportion of AG mutations was highest in the G misincorporation library, and some unexpected point mutations appeared in the dTTPαs and dCTPαs libraries.

2. Screening and Identification of Alkaline Stability Mutants of Subtilisin

It is possible to screen colonies producing subtilisin by halos of casein digestion (Wells, J.A. et al. (1983) Nucleic Acids Res., 11, 7911-7925). However, two problems were posed by screening colonies under high alkaline conditions (>pH 11). First, B. subtilis

will not grow at high pH, and we have been unable to transform an alkylophilic strain of bacillus. This problem was overcome by adopting a replica plating strategy in which colonies were grown on filters at neutral pH to produce subtilisin and filters subsequently transferred to casein plates at pH 11.5 to assay subtilisin activity. However, at pH 11.5 the casein micells no longer formed a turbid background and thus prevented a clear observation of proteolysis halos. The problem was overcome by briefly staining the plate with Coomassie blue to amplify proteolysis zones and acidifying the plates to develop casein micell turbidity. By comparison of the halo size produced on the reference growth plate (pH 7) to the high pH plate (pH 11.5), it was possible to identify mutant subtilisins that had increased (positives) or decreased (negatives) stability under alkaline conditions.

Roughly 1000 colonies were screened from each of the four misincorporation libraries. The percentage of colonies showing a differential loss of activity at pH 11.5 versus pH 7 represented 1.4, 1.8, 1.4, and 0.6% of the total colonies screened from the thiol dGTPαs, dATPαs, dTTPαs, and dCTPαs libraries, respectively. Several of these negative clones were sequenced and all were found to contain a single base change as expected from the misincorporation library from which they came. Negative mutants included A36, E170 and V50. Two positive mutants were identified as V107 and R213. The ratio of negatives to positives was roughly 50:1.

3. Stability and Activity of Subtilisin Mutants at Alkaline pH

Subtilisin mutants were purified and their autolytic stabilities were measured by the time course of inactivation at pH 12.0 (Figs. 32 and 33). Positive mutants identified from the screen (i.e., V107 and R213) were more resistant to alkaline induced autolytic inactivation compared to wild-type; negative mutants (i.e., E170 and V50) were less resistant. We had advantageously produced another mutant at position 50 (F50) by site-directed mutagenesis. This mutant was more stable than wild-type enzyme to alkaline autolytic inactivation (Fig. 33) At the termination of the autolysis study, SDS-PAGE analysis confirmed that each subtilisin variant had autolyzed to an extent consistent with the remaining enzyme activity.

The stabilizing effects of V107, R213, and F50 are cumulative. See Table XXI. The double mutant, V107/R213 (made by subcloning the 920 bp EcoRI-KpnI fragment of pB0180V107 into the 6.6 kb EcoRI-KpnI fragment of pB0180R213), is more stable than either single mutant. The triple mutant, F50/V107/R213 (made by subcloning the 735 bp EcoRI-PvuII fragment of pF50 (Example 2) into the 6.8 kb EcoRI-PvuII fragment of pB0180/V107, is more stable than the double mutant V107/R213 or F50. The inactivation curves show a biphasic character that becomes more pronounced the more stable the mutant analyzed. This may result from some destablizing chemical modification(s) (eg., deamidation) during the autolysis study and/or reduced stabilization caused by complete digestion of larger autolysis peptides. These alkaline autolysis studies have been repeated on separately purified enzyme batches with essentially the same results. Rates of autolysis should depend both on the conformational

F. Random Cassette Mutagenesis of Residues 197 through 228

Plasmid pΔ222 (Wells, et al. (1985) Gene 34, 315-323) was digested with PstI and BamHI and the 0.4 kb PstI/BamHI fragment (fragment 1, see Fig. 34) purified from a polyacrylamide gel by electroelution.

The 1.5 kb EcoRI/BamHI fragment from pS4.5 was cloned into M13mp9. Site directed mutagenesis was performed to create the A197 mutant and simultaneously insert a silent SstI site over codons 195-196. The mutant EcoRI/BamHI fragment was cloned back into pBS42. The pA197 plasmid was digested with BamHI and SstI and the 5.3 kb BamHI/SstI fragment (fragment 2) was purified from low melting agarose.

Complimentary oligonucleotides were synthesized to span the region from SstI (codons 195-196) to PstI (codons 228-230). These oligodeoxynucleotides were designed to (1) restore codon 197 to the wild type, (2) re-create a silent KpnI site present in pΔ222 at codons 219-220, (3) create a silent SmaI site over codons 210-211, and (4) eliminate the PstI site over codons 228-230 (see Fig. 35). Oligodeoxynucleotides were synthesized with 2% contaminating nucleotides at each cycle of synthesis, e.g., dATP reagent was spiked with 2% dCTP, 2% dGTP, and 2% dTTP. For 97-mers, this 2% poisoning should give the following percentages of non-mutant, single mutants and double or higher mutants per strand with two or more misincorporations per complimentary strand: 14% non-mutant, 28% single mutant, and 57% with ≥2 mutations, according to the general formula

$$f = \frac{\mu^n}{n!} e^{-\mu} .$$

where μ is the average number of mutations and n is a number class of mutations and f is the fraction of the total having that number of mutations. Complimentary oligodeoxynucleotide pools were phosphorylated and annealed (fragment 3) and then ligated at 2-fold molar excess over fragments 1 and 2 in a three-way ligation.

E. coli MM294 was transformed with the ligation reaction, the transformation pool grown up over night and the pooled plasmid DNA was isolated. This pool represented 3.4×10^4 independent transformants. This plasmid pool was digested with PstI and then used to retransform E. coli. A second plasmid pool was prepared and used to transform B. subtilis (BG2036). Approximately 40% of the BG2036 transformants actively expressed subtilisin as judged by halo-clearing on casein plates. Several of the non-expressing transformants were sequenced and found to have insertions or deletions in the synthetic cassettes. Expressing BG2036 mutants were arrayed in microtiter dishes with 150μl of LB/12.5μg/mL chloramphenicol (cmp) per well, incubated at 37°C for 3-4 hours and then stamped in duplicate onto nitrocellulose filters laid on LB 1.5% skim milk/5μg/mL cmp plates and incubated overnight at 33°C (until halos were approximately 4-8 mm in diameter). Filters were then lifted to stacks of filter paper saturated with 1 x Tide commercial grade detergent, 50 mM Na_2CO_3, pH 11.5 and incubated at 65°C for 90 min. Overnight growth plates were Commassie stained and destained to establish basal levels of expression. After this treatment, filters were returned to pH7/skim milk/20μg/mL tetracycline plates and incubated at 37°C for 4 hours to overnight.

Mutants identified by the high pH stability screen to be more alkaline stable were purified and analyzed for autolytic stability at high pH or high temperature. The double mutant C204/R213 was more stable than wild type at either high pH or high temperature (Table XXII).

This mutant was dissected into single mutant parents (C204 and R213) by cutting at the unique SmaI restriction site (Fig. 35) and either ligating wild type sequence 3' to the SmaI site to create the single C204 mutant or ligating wild type sequence 5' to the SmaI site to create the single R213 mutant. Of the two single parents, C204 was nearly as alkaline stable as the parent double mutant (C04/R213) and slightly more thermally stable. See Table XXII. The R213 mutant was only slightly more stable than wild type under both conditions (not shown).

Another mutant identified from the screen of the 197 to 228 random cassette mutagenesis was R204. This mutant was more stable than wild type at both high pH and high temperature but less stable than C204.

TABLE XXII

Stability of subtilisin variants

Purified enzymes (200μg/mL) were incubated in 0.1M phosphate, pH 12 at 30°C for alkaline autolysis, or in 2mM $CaCl_2$, 50mM MOPS, pH 7.0 at 62°C for thermal autolysis. At various times samples were assayed for residual enzyme activity. Inactivations were roughly pseudo-first order, and t 1/2 gives the time it took to reach 50% of the starting activity in two separate experiments.

Subtilisin variant	t 1/2 (alkaline autolysis) Exp. #1	t 1/2 (alkaline autolysis) Exp. #2	t 1/2 (thermal autolysis) Exp. #1	t 1/2 (thermal autolysis) Exp. #2
wild type	30	25	20	23
F50/V107/R213	49	41	18	23
R204	35	32	24	27
C204	43	46	38	40
C204/R213	50	52	32	36
L204/R213	32	30	20	21

G. Random Mutagenesis at Codon 204

Based on the above results, codon 204 was targeted for random mutagenesis. Mutagenic DNA cassettes (for codon at 204) all contained a fixed R213 mutation which was found to slightly augment the stability of the C204 mutant.

Plasmid DNA encoding the subtilisin mutant C204/R213 was digested with SstI and EcoRI and a 1.0 kb EcoRI/SstI fragment was isolated by electro-elution from polyacrylamide gel (fragment 1, see Fig. 35).

C204/R213 was also digested with SmaI and EcoRI and the large 4.7 kb fragment, including vector sequences and the 3' portion of coding region, was isolated from low melting agarose (fragment 2, see Fig. 36).

Fragments 1 and 2 were combined in four separate three-way ligations with heterophosphorylated fragments 3 (see Figs. 36 and 37). This hetero-phosphorylation of synthetic duplexes should preferentially drive the phosphorylated strand into the plasmid ligation product. Four plasmid pools, corresponding to the four ligations, were restricted with SmaI in order to linearize any single cut C204/R213 present from fragment 2 isolation, thus reducing the background of C204/R213. E. coli was then re-transformed with SmaI-restricted plasmid pools to yield a second set of plasmid pools which are essentially free of C204/R213 and any non-segregated heterduplex material.

These second enriched plasmid pools were then used to transform B. subtilis (BG2036) and the resulting four mutant pools were screened for clones expressing subtilisin resistant to high pH/temperature inactivation. Mutants found positive by such a screen were further characterized and identified by sequencing.

The mutant L204/R213 was found to be slightly more stable than the wild type subtilisin. See Table XXII.

Having described the preferred embodiments of the present invention, it will appear to those ordinarily skilled in the art that various modifications may be made to the disclosed embodiments, and that such modifications are intended to be within the scope of the present invention.

CLAIMS;

1. A carbonyl hydrolase mutant having at least one property which is substantially different from the same property of a precursor carbonyl hydrolase from which the amino acid sequence of said carbonyl hydrolase mutant is derived, said property being selected from the group consisting of thermal stability and alkaline stability wherein said precursor carbonyl hydrolase is selected from the group consisting of naturally occurring carbonyl hydrolases and recombinant carbonyl hydrolases and said carbonyl hydrolase mutant amino acid sequence is derived by a method selected from the group consisting of the substitution, deletion and insertion of at least one amino acid in said amino acid sequence of said precursor carbonyl hydrolase.

2. A carbonyl hydrolase mutant having at least one property which is substantially different from the same property of a precursor carbonyl hydrolase from which the amino acid sequence of said carbonyl hydrolase mutant is derived, said property being selected from the group consisting of oxidative stability, substrate specificity, catalytic activity, thermal stability, alkaline stability and pH activity profile wherein said precursor carbonyl hydrolase is selected from the group consisting of naturally occurring carbonyl hydrolases and recombinant carbonyl hydrolases and said carbonyl hydrolase mutant amino acid sequence is derived by a method selected from the group consisting of deletion and insertion of at least one amino acid in said amino acid sequence of said precursor carbonyl hydrolase and substitution of more than one amino acid residue of said amino acid sequence of said precursor carbonyl hydrolase.

3. A carbonyl hydrolase mutant derived by the replacement of at least one amino acid residue of a precursor carbonyl hydrolase with a different amino acid, said one amino acid residue being selected from the group of amino acid residues of Bacillus amyloliquefaciens subtilisin consisting of Tyr21, Thr22, Ser24, Ser33, Asp36, Ala45, Gly46, Ala48, Ser49, Met50, Asn77, Ser87, Lys94, Val95, Leu96, Tyr104, Ile107, Gly110, Met124, Asn155, Glu156, Lys170, Tyr171, Pro172, Phe189, Asp197, Met199, Ser204, Lys213, Tyr217, Ser221, His67, Leu126, Leu135, Gly97, Asp99, Ser101, Gly102, Glu103, Leu126, Gly127, Gly128, Pro129, Tyr214, Gly215, and equivalent amino acid residues in other precursor carbonyl hydrolases.

4. A carbonyl hydrolase mutant having an amino acid sequence derived from the amino acid sequence of a precursor carbonyl hydrolase by the substituion of a differnt amino acid for more than one amino acid residue of said amino acid sequence of said precursor carbonyl hydrolase, said amino acid residues being selected from the group of amino acid residues of Bacillus amyloliquefaciens subtilisin consisting of Tyr21, Thr22, Ser24, Asp32, Ser33, Asp36, Ala45, Gly46, Ala48, Ser49, Met50, Asn77, Ser87, Lys94, Val95, Leu96, Tyr104, Ile107, Gly110, Met124, Ala152, Asn-155, Glu156, Gly166, Gly169, Lys170, Tyr171, Pro172, Phe189, Asp197, Met199, Ser204, Lys213, Tyr217, Ser221, Met222, His67, Leu126, Leu135, Gly97, Asp99, Ser101, Gly102, Glu103, Leu126, Gly127, Gly128, Pro129, Tyr214, Gly215, and equivalent amino acid residues in other precursor carbonyl hydrolases.

5. The mutant of Claim 4 wherein said combinations are selected from the group consisting of Thr22/Ser87, Ser24/Ser87, Ala45/Ala48, Ser49/Lys94, Ser49/Val95, Met50/Val95, Met50/Gly110, Met50/Met124, Met50/Met222, Met124/Met222, Glu156/Gly166, Glu156/Gly169, Gly166/Met222, Gly169/Met222, Tyr21/Thr22, Met50/Met124/Met222, Tyr21/Thr22/Ser87, Met50/Glu156/Gly166/Tyr217, Met50/Glu156/Tyr217, Glu156/Gly169/Tyr217, Ile170/Lys213, Ser204/Lys213, Met50/Ile107/Lys213 and Ser24/Met50/Ile107/Glu156/Gly166/Gly169/Ser204/Lys213/Gly215/Tyr217.

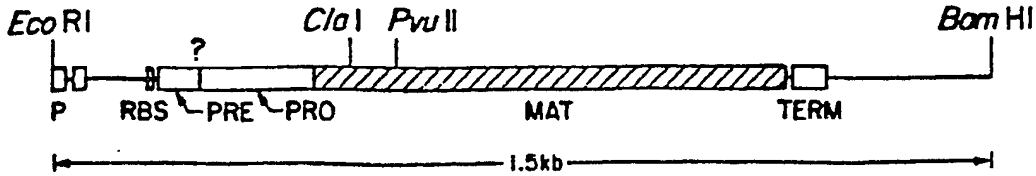
6. A carbonyl hydrolase mutant derived by the replacement of at least one amino acid residue of a precursor carbonyl hydrolase with a different amino acid, said one amino acid residue being selected from the group of amino acid residues of of Bacillus amyloliquefaciens subtilisin consisting of Tyr21, Thr22, Ser24, Asp32, Ser33, Asp36, Ala45, Gly46, Ala48, Ser49, Met50, Asn77, Ser87, Lys94, Val95, Leu96, Tyr104, Ile107, Gly110, Met124, Ala152, Asn-155, Glu156, Gly166, Gly169, Lys170, Tyr171, Pro172, Phe189, Asp197, Met199, Ser204, Lys213, Tyr217, Ser221, Met222, His67, Leu126, Leu135, Gly97, Asp99, Ser101, Gly102, Glu103, Leu126, Gly127, Gly128, Pro129, Tyr214, Gly215, and equivalent amino acid residues in other precursor carbonyl hydrolases, wherein said at least one amino acid residue of said precursor carbonyl hydrolase is replaced with the amino acid residues listed in TABLE I and TABLE II herein.

7. The mutant of Claim 6 wherein the amino acid replacing said at least one amino acid residue in said precursor carbonyl hydrolase is selectd from the replacement amino acids listed in TABLE I herein.

8. Mutant DNA sequence encoding the mutant of claims 1 through 7.

9. Expression vector containing the mutant DNA sequence of claim 8.

10. Host cell transformed with the expression vector of Claim 9.



(5) (3) (4)
P RBS -107 fMet
1 GGTCTACTAAAATATTATTCCATACTATACAATTAATACACAGAATAATCTGTCTATTGGTTATTCTGCAAATGAAAAAAAGGAGAGGATAAAGA GTG

-100 PRE -90
Arg Gly Lys Lys Val Trp Ile Ser Leu Leu Phe Ala Leu Ala Leu Ile Phe Thr Met Ala Phe Gly Ser Thr Ser
99 AGA GGC AAA AAA GTA TGG ATC AGT TTG CTG TTT GCT TTA GCG TTA ATC TTT ACG ATG GCG TTC GGC AGC ACA TCC

-80 -70 PRO -60
Ser Ala Gln Ala Ala Gly Lys Ser Asn Gly Glu Lys Lys Tyr Ile Val Gly Phe Lys Gln Thr Met Ser Thr Met
174 TCT GCC CAG GCG GCA GGG AAA TCA AAC GGG GAA AAG AAA TAT ATT GTC GGG TTT AAA CAG ACA ATG AGC ACG ATG

-50 -40
Ser Ala Ala Lys Lys Lys Asp Val Ile Ser Glu Lys Gly Gly Lys Val Gln Lys Gln Phe Lys Tyr Val Asp Ala
249 AGC GCC GCT AAG AAG AAA GAT GTC ATT TCT GAA AAA GGC GGG AAA GTG CAA AAG CAA TTC AAA TAT GTA GAC GCA

-30 -20 -10
Ala Ser Ala Thr Leu Asn Glu Lys Ala Val Lys Glu Leu Lys Lys Asp Pro Ser Val Ala Tyr Val Glu Glu Asp
324 GCT TCA GCT ACA TTA AAC GAA AAA GCT GTA AAA GAA TTG AAA AAA GAC CCG AGC GTC GCT TAC GTT GAA GAA GAT

-1 1 → MAT 10
His Val Ala His Ala Tyr Ala Gln Ser Val Pro Tyr Gly Val Ser Gln Ile Lys Ala Pro Ala Leu His Ser Gln
399 CAC GTA GCA CAT GCG TAC GCG CAG TCC GTG CCT TAC GGC GTA TCA CAA ATT AAA GCC CCT GCT CTG CAC TCT CAA

20 30 40
Gly Tyr Thr Gly Ser Asn Val Lys Val Ala Val Ile Asp Ser Gly Ile Asp Ser Ser His Pro Asn Leu Lys Val
474 GGC TAC ACT GGA TCA AAT GTT AAA GTA GCG GTT ATC GAC AGC GGT ATC GAT TCT TCT CAT CCT GAT TTA AAG GTA

50 Pro Asn 60 Asp
Ala Gly Gly Ala Ser Met Val Pro Ser Glu Thr Asn Pro Phe Gln Asn Asn Asn Ser His Gly Thr His Val Ala
549 GCA GGC GGA GCC AGC ATG GTT CCT TCT GAA ACA AAT CCT TTC CAA GAC AAC AAC TCT CAC GGA ACT CAC GTT GCC

70 80 Ser Ala 90
Gly Thr Val Ala Ala Leu Asn Asn Ser Ile Gly Val Leu Gly Val Ala Pro Ser Ala Ser Leu Tyr Ala Val Lys
624 GGC ACA GTT GCG GCT CTT AAT AAC TCA ATC GGT GTA TTA GGC GTT GCG CCA AGC GCA TCA CTT TAC GCT GTA AAA

Asp Ala 100 110
Val Leu Gly Ala Asp Gly Ser Gly Gln Tyr Ser Trp Ile Ile Asn Gly Ile Glu Trp Ala Ile Ala Asn Asn Met
699 GTT CTC GGT GCT GAC GGT TCC GGC CAA TAC AGC TGG ATC ATT AAC GGA ATC GAG TGG GCG ATC GCA AAC AAT ATG

120 130 140
Asp Val Ile Asn Met Ser Leu Gly Gly Pro Ser Gly Ser Ala Ala Leu Lys Ala Ala Val Asn Lys Ala Val Ala
774 GAC GTT ATT AAC ATG AGC CTC GGC GGA CCT TCT GGT TCT GCT GCT TTA AAA GCG GCA GTT GAT AAA GCC GTT GCA

150 Ser Thr 160
Ser Gly Val Val Val Val Ala Ala Ala Gly Asn Glu Gly Thr Ser Gly Ser Ser Ser Thr Val Gly Tyr Pro Gly
849 TCC GGC GTC GTA GTC GTT GCG GCA GCC GGT AAC GAA GGC ACT TCC GGC AGC TCA AGC ACA GTG GGC TAC CCT GGT

170 180 190
Lys Tyr Pro Ser Val Ile Ala Val Gly Ala Val Asn Ser Ser Asn Gln Arg Ala Ser Phe Ser Ser Val Gly Pro
924 AAA TAC CCT TCT GTC ATT GCA GTA GGC GCT GTT GAC AGC AGC AAC CAA AGA GCA TCT TTC TCA AGC GTA GGA CCT

200 210
Glu Leu Asp Val Met Ala Pro Gly Val Ser Ile Gln Ser Thr Leu Pro Gly Asn Lys Tyr Gly Ala Tyr Asn Gly
999 GAG CTT GAT GTC ATG GCA CCT GGC GTA TCT ATC CAA AGC ACG CTT CCT GGA AAC AAA TAC GGG GCG TAC AAC GGT

220 230 240
Thr Ser Met Ala Ser Pro His Val Ala Gly Ala Ala Ala Leu Ile Leu Ser Lys His Pro Asn Trp Thr Asn Thr
1074 ACG TCA ATG GCA TCT CCG CAC GTT GCC GGA GCG GCT GCT TTG ATT CTT TCT AAG CAC CCG AAC TGG ACA AAC ACT

250 Gln 260
Gln Val Arg Ser Ser Leu Glu Asn Thr Thr Thr Lys Leu Gly Asp Ser Phe Tyr Tyr Gly Lys Gly Leu Ile Asn
1149 CAA GTC CGC AGC AGT TTA GAA AAC ACC ACT ACA AAA CTT GGT GAT TCT TTC TAC TAT GGA AAA GGG CTG ATC AAC

270 275 TERM
Val Gln Ala Ala Ala Gln OC
1224 GTA CAG GCG GCA GCT CAG TAA AACATAAAAAACCGGCCTTGGCCCCGCCGGTTTTTTATTATTTTTCTTCCTCCGCATGTTCAATCCGCTCC

1316 ATAATCGACGGATGGCTCCCTCTGAAAATTTTAACGAGAAACGGCGGGTTGACCCGGCTCAGTCCCGTAACGGCCAAGTCCTGAAACGTCTCAATCGCCG

1416 CTTCCCGGTTTCCGGTCAGCTCAATGCCGTAACGGTCGGCGGCGTTTTCCTGATACCGGGAGACGGCATTCGTAATCGGATC

FIG.—1

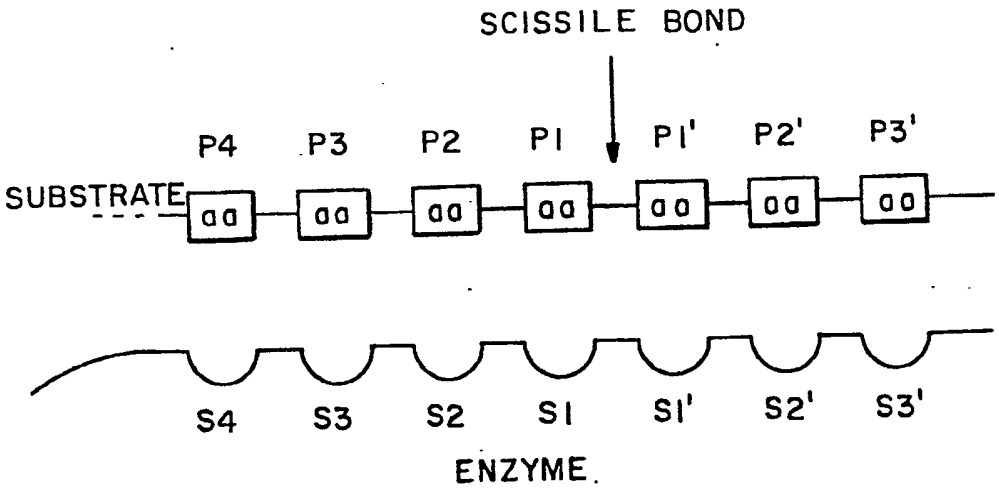

SCISSILE BOND
P4
P3
P2
P1
P1'
P2'
P3'
SUBSTRATE
aa
S4
S3
S2
S1
S1'
S2'
S3'
ENZYME.

FIG.—2

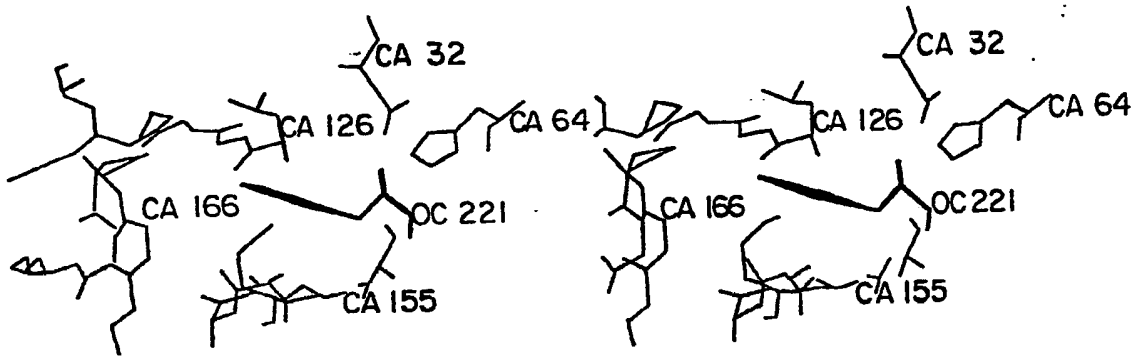

CA 32
CA 126
CA 64
CA 166
OC 221
CA 155
CA 32
CA 126
CA 64
CA 166
OC 221
CA 155

FIG.—3

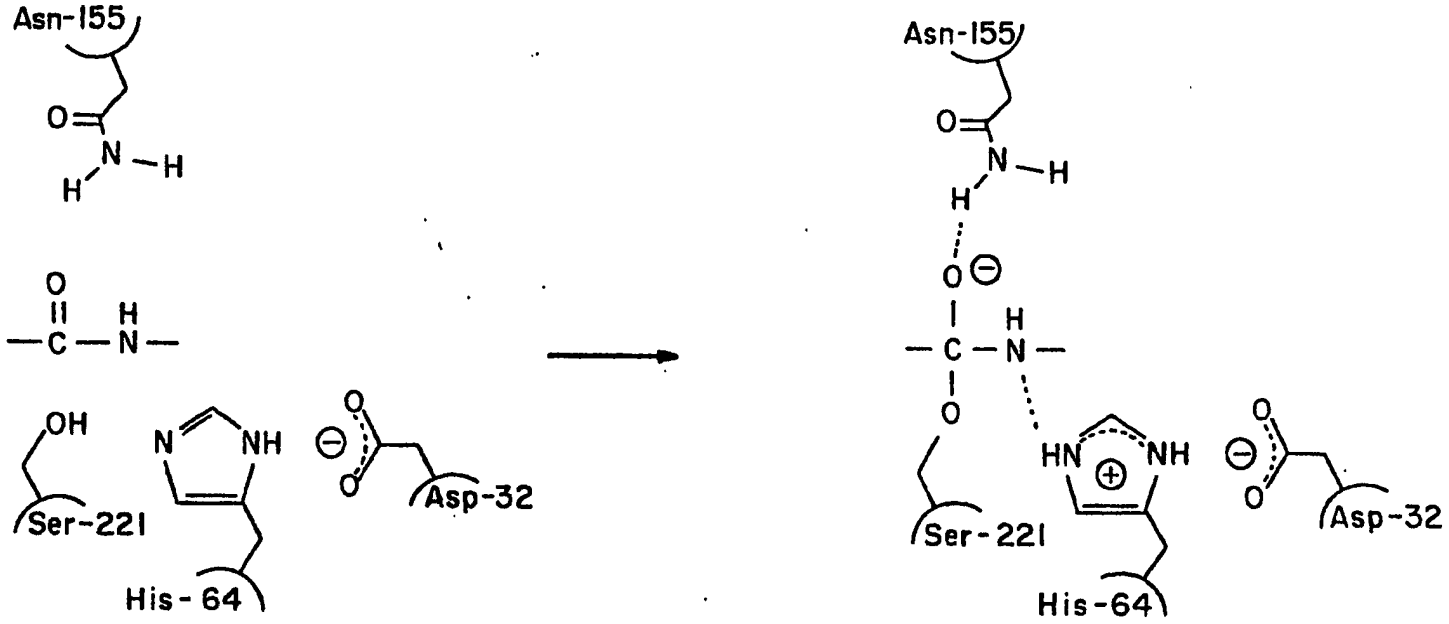


FIG.—4

0251446

Homology of Bacillus proteases

1.Bacillus amyloliquifaciens
2.Bacillus subtilis var.I168
3.Bacillus licheniformis (carlsbergensis)

1									10									20
A	Q	S	V	P	Y	G	V	S	Q	I	K	A	P	A	L	H	S	Q	G
A	Q	S	V	P	Y	G	I	S	Q	I	K	A	P	A	L	H	S	Q	G
A	Q	T	V	P	Y	G	I	P	L	I	K	A	D	K	V	Q	A	Q	G

21									30									40
Y	T	G	S	N	V	K	V	A	V	I	D	S	G	I	D	S	S	H	P
Y	T	G	S	N	V	K	V	A	V	I	D	S	G	I	D	S	S	H	P
F	K	G	A	N	V	K	V	A	V	L	D	T	G	I	Q	A	S	H	P

41									50									60
D	L	K	V	A	G	G	A	S	M	V	P	S	E	T	N	P	F	Q	D
D	L	N	V	R	G	G	A	S	F	V	P	S	E	T	N	P	Y	Q	D
D	L	N	V	V	G	G	A	S	F	V	A	G	E	A	Y	N	T	•	D

61									70									80
N	N	S	H	G	T	H	V	A	G	T	V	A	A	L	N	N	S	I	G
G	S	S	H	G	T	H	V	A	G	T	I	A	A	L	N	N	S	I	G
G	N	G	H	G	T	H	V	A	G	T	V	A	A	L	D	N	T	T	G

81									90									100
V	L	G	V	A	P	S	A	S	L	Y	A	V	K	V	L	G	A	D	G
V	L	G	V	S	P	S	A	S	L	Y	A	V	K	V	L	D	S	T	G
V	L	G	V	A	P	S	V	S	L	Y	A	V	K	V	L	N	S	S	G

101									110									120
S	G	Q	Y	S	W	I	I	N	G	I	E	W	A	I	A	N	N	M	D
S	G	Q	Y	S	W	I	I	N	G	I	E	W	A	I	S	N	N	M	D
S	G	S	Y	S	G	I	V	S	G	I	E	W	A	T	T	N	G	M	D

FIG.—5A-1

```
121                                                 130                                                 140
V  I  N  M  S  L  G  G  P  S  G  S  A  A  L  K  A  A  V  D
V  I  N  M  S  L  G  G  P  T  G  S  T  A  L  K  T  V  V  D
V  I  N  M  S  L  G  G  A  S  G  S  T  A  M  K  Q  A  V  D

141                                                 150                                                 160
K  A  V  A  S  G  V  V  V  V  A  A  A  G  N  E  G  T  S  G
K  A  V  S  S  G  I  V  V  A  A  A  A  G  N  E  G  S  S  G
N  A  Y  A  R  G  V  V  V  V  A  A  A  G  N  S  G  N  S  G

161                                                 170                                                 180
S  S  S  T  V  G  Y  P  G  K  Y  P  S  V  I  A  V  G  A  V
S  T  S  T  V  G  Y  P  A  K  Y  P  S  T  I  A  V  G  A  V
S  T  N  T  I  G  Y  P  A  K  Y  D  S  V  I  A  V  G  A  V

181                                                 190                                                 200
D  S  S  N  Q  R  A  S  F  S  S  V  G  P  E  L  D  V  M  A
N  S  S  N  Q  R  A  S  F  S  S  A  G  S  E  L  D  V  M  A
D  S  N  S  N  R  A  S  F  S  S  V  G  A  E  L  E  V  M  A

201                                                 210                                                 220
P  G  V  S  I  Q  S  T  L  P  G  N  K  Y  G  A  Y  N  G  T
P  G  V  S  I  Q  S  T  L  P  G  G  T  Y  G  A  Y  N  G  T
P  G  A  G  V  Y  S  T  Y  P  T  N  T  Y  A  T  L  N  G  T

221                                                 230                                                 240
S  M  A  S  P  H  V  A  G  A  A  A  L  I  L  S  K  H  P  N
S  M  A  T  P  H  V  A  G  A  A  A  L  I  L  S  K  H  P  T
S  M  A  S  P  H  V  A  G  A  A  A  L  I  L  S  K  H  P  N

241                                                 250                                                 260
W  T  N  T  Q  V  R  S  S  L  E  N  T  T  T  K  L  G  D  S
W  T  N  A  Q  V  R  D  R  L  E  S  T  A  T  Y  L  G  N  S
L  S  A  S  Q  V  R  N  R  L  S  S  T  A  T  Y  L  G  S  S

261                                                 270
F  Y  Y  G  K  G  L  I  N  V  Q  A  A  A  Q
F  Y  Y  G  K  G  L  I  N  V  Q  A  A  A  Q
F  Y  Y  G  K  G  L  I  N  V  E  A  A  A  Q
```

FIG.—5A—2

ALIGNMENT OF B.AMYLOLIQUIFACIENS SUBTILISIN AND THERMITASE
1.B.amyloliquifaciens subtilisin
2.thermitase

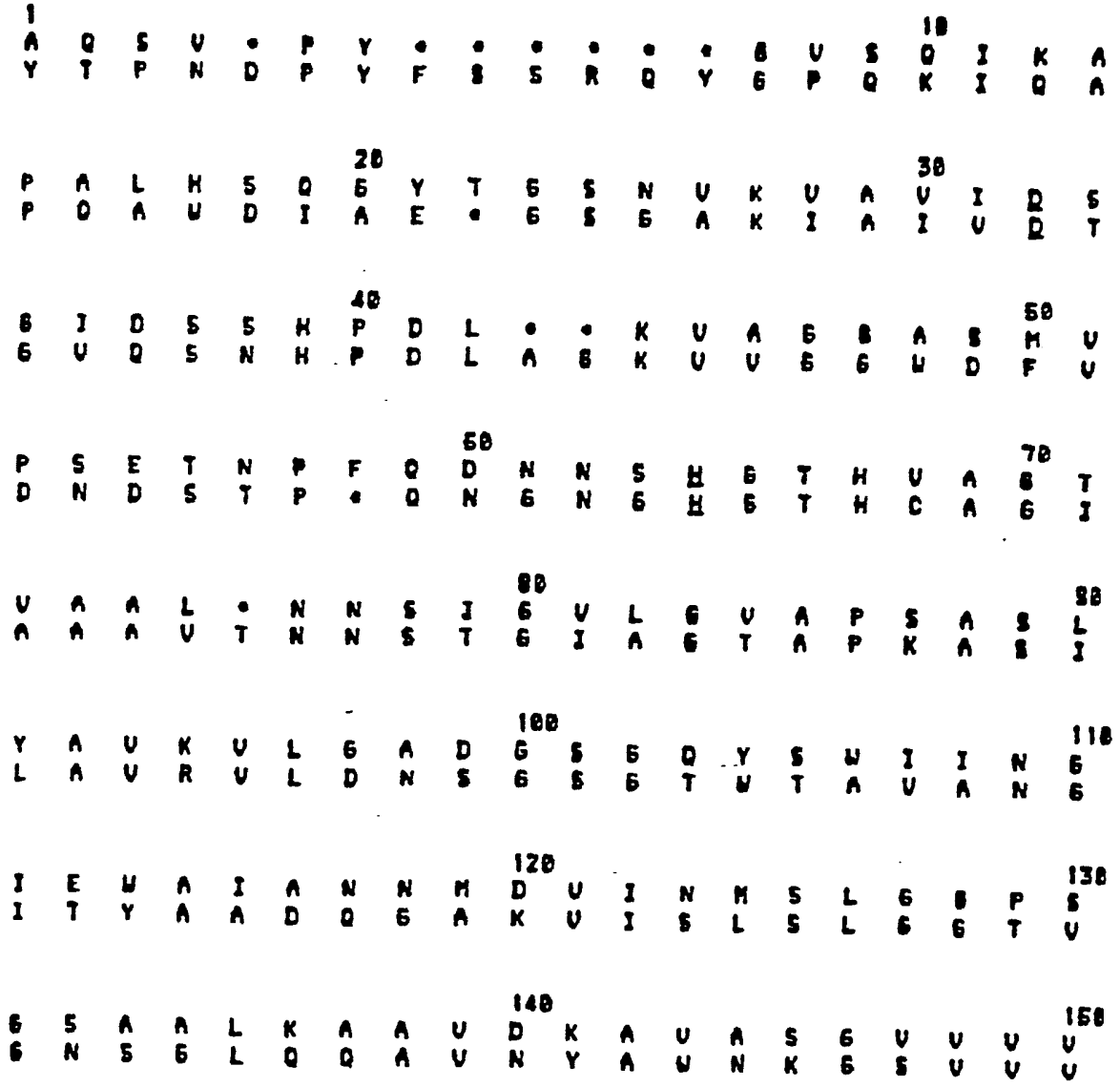


FIG.—5B—1

									160									170
A	A	A	G	N	E	G	T	S	G	S	S	S	T	V	G	Y	P	G	K
A	A	A	G	N	A	G	N	T	A	•	•	•	•	P	N	Y	P	A	Y

									180									190
Y	P	S	V	I	A	V	G	A	V	D	S	S	N	Q	R	A	S	F	S
Y	S	N	A	I	A	V	A	S	T	D	Q	N	D	N	K	S	S	F	S

									200									210
S	V	G	P	E	L	D	V	K	A	P	G	V	S	I	Q	S	T	L	P
T	Y	G	S	V	V	D	V	A	A	P	G	S	W	I	Y	S	T	Y	P

									220									230
G	N	K	Y	G	A	y	N	G	T	S	M	A	S	P	H	V	A	G	A
T	S	T	Y	A	S	L	S	G	T	S	M	A	T	P	H	V	A	G	V

									240									250
A	A	L	I	L	S	K	H	P	N	V	T	N	T	Q	V	R	S	S	L
A	G	L	L	A	S	Q	G	R	S	•	•	A	S	N	I	R	A	A	I

										260								
E	N	T	T	T	K	•	L	G	D	S	F	Y	Y	G	K	G	L	I	N
E	N	T	A	D	K	I	S	G	T	G	T	Y	W	A	K	G	R	V	N

270						
V	Q	A	A	A	Q	
A	Y	K	A	V	Q	Y

FIG.—5B-2

TOTALLY CONSERVED RESIDUES IN SUBTILISINS

```
1                                  10                                  20
.   .   .   .   P   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .

21                                 30                                  40
.   .   G   .   .   .   .   .   .   .   .   D   .   G   .   .   .   .   H   .

41                                 50                                  60
.   .   .   .   .   G   .   .   .   .   V   .   .   .   .   .   .   .   .   .

61                                 70                                  80
.   .   .   H   G   T   H   .   .   G   .   .   .   .   .   .   .   .   .   .

81                                 90                                  100
.   .   G   .   .   .   .   .   .   .   .   .   .   .   V   L   .   .   .   G

101                                110                                 120
S   G   .   .   .   .   .   .   .   G   .   .   .   .   .   .   .   .   .   .

121                                130                                 140
.   .   .   .   .   L   G   .   .   .   .   .   .   .   .   .   .   .   .   .

141                                150                                 160
.   .   .   .   .   G   .   .   .   .   .   .   .   G   N   .   .   .   .   .

161                                170                                 180
.   .   .   .   .   .   Y   P   .   .   .   .   .   .   .   .   V   .   .   .

181                                190                                 200
.   .   .   .   .   .   .   S   F   S   .   .   .   .   .   .   .   .   .   .

201                                210                                 220
P   G   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   G   T

221                                230                                 240
S   M   A   .   P   H   V   A   G   .   .   .   .   .   .   .   .   .   .   .

241                                250                                 260
.   .   .   .   .   .   R   .   .   .   .   .   .   .   .   .   .   .   .   .

261                                270
.   .   .   .   .   .   .   .   N   .   .   .   .   .   .
```

FIG.—5C

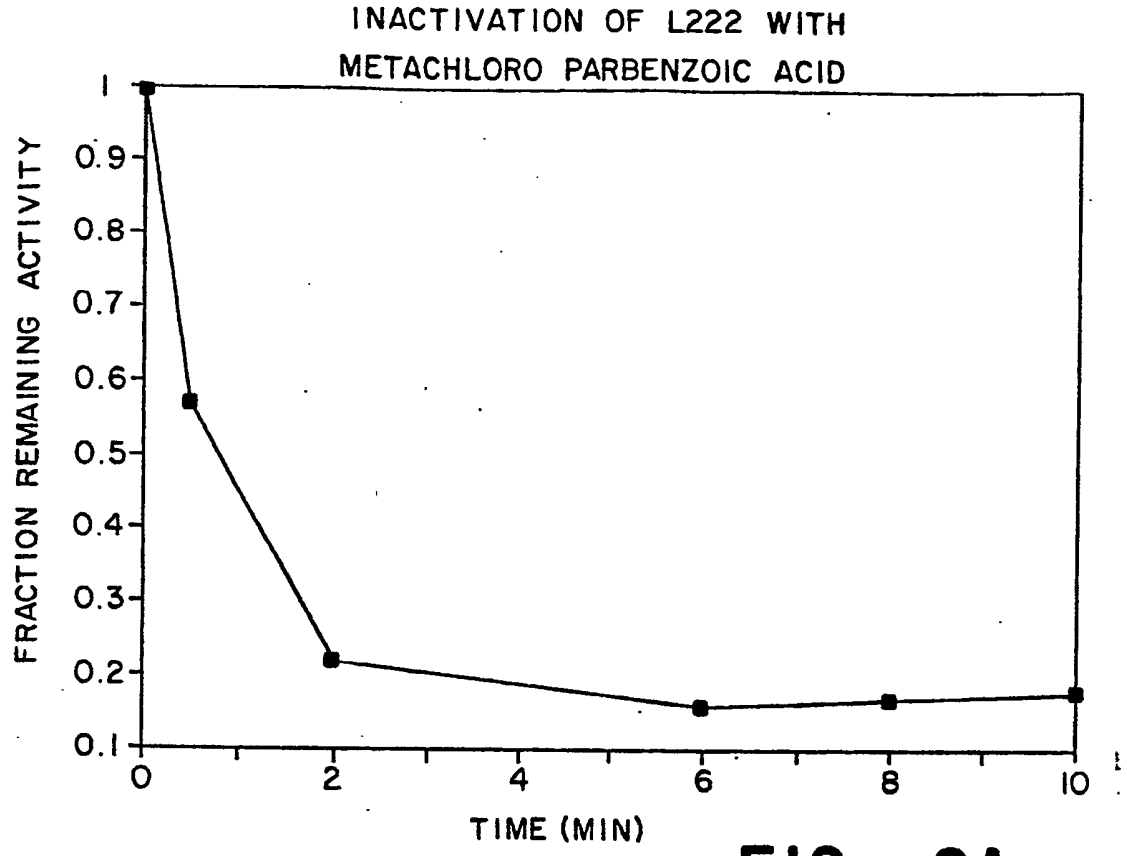

INACTIVATION OF L222 WITH
METACHLORO PARBENZOIC ACID
FRACTION REMAINING ACTIVITY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
4
6
8
10
TIME (MIN)

FIG.—6A

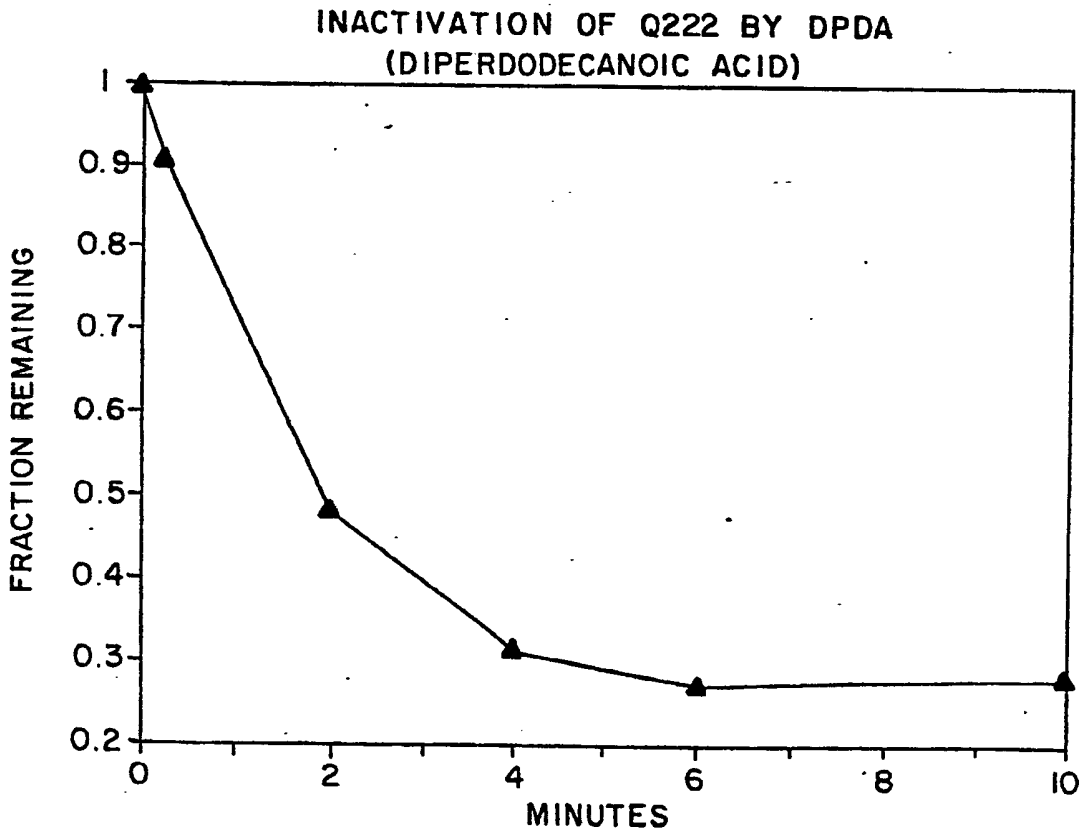

INACTIVATION OF Q222 BY DPDA
(DIPERDODECANOIC ACID)
FRACTION REMAINING
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
2
4
6
8
10
MINUTES

FIG.—6B

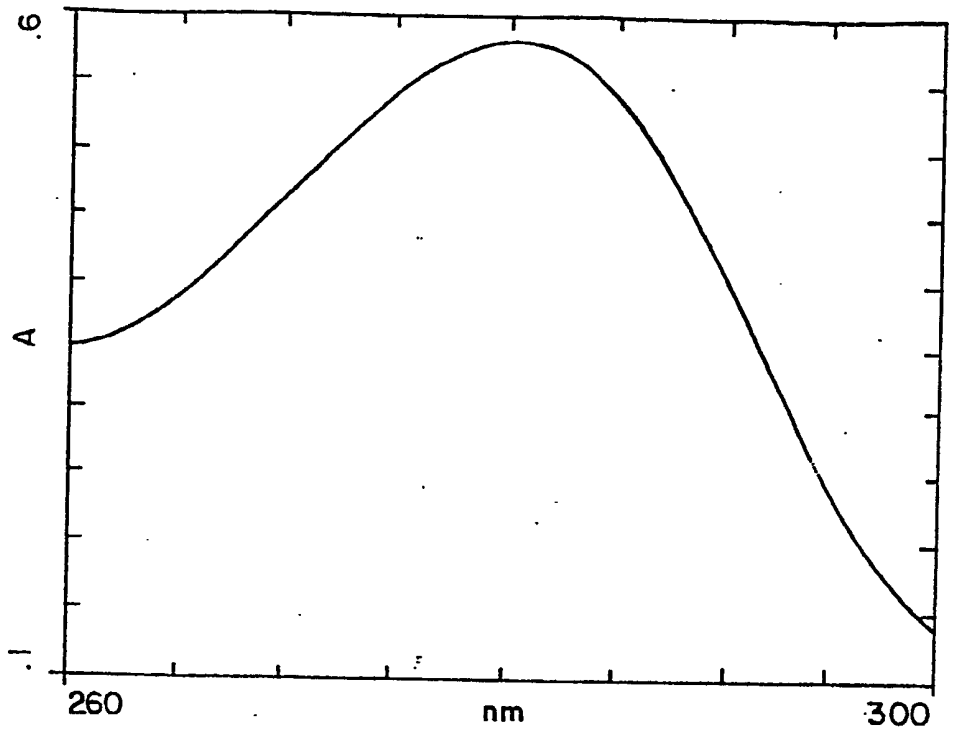


FIG. —7A

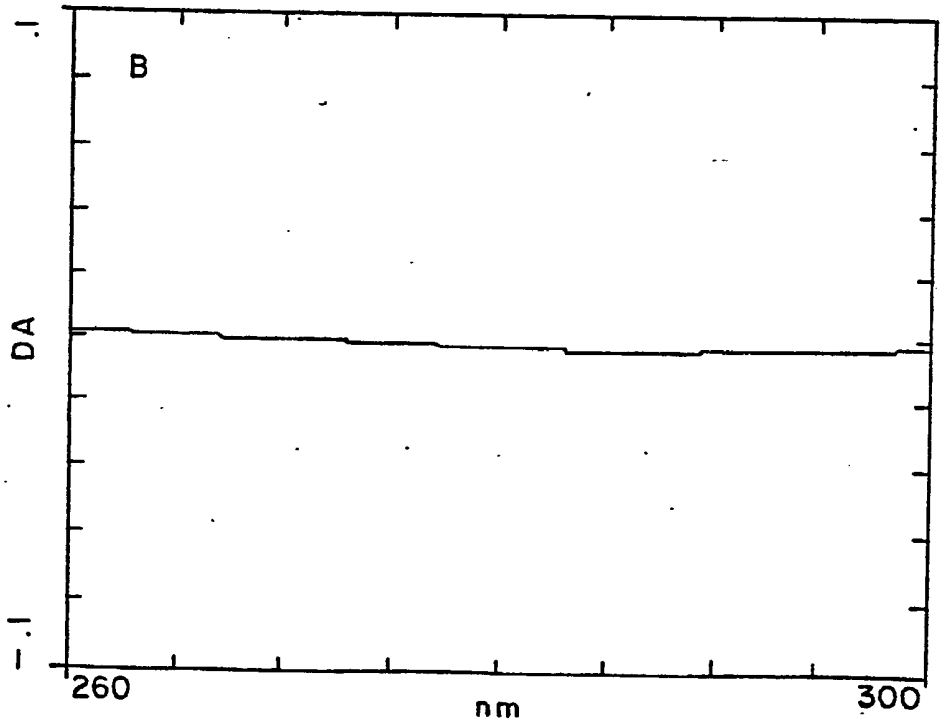


FIG. — 7B

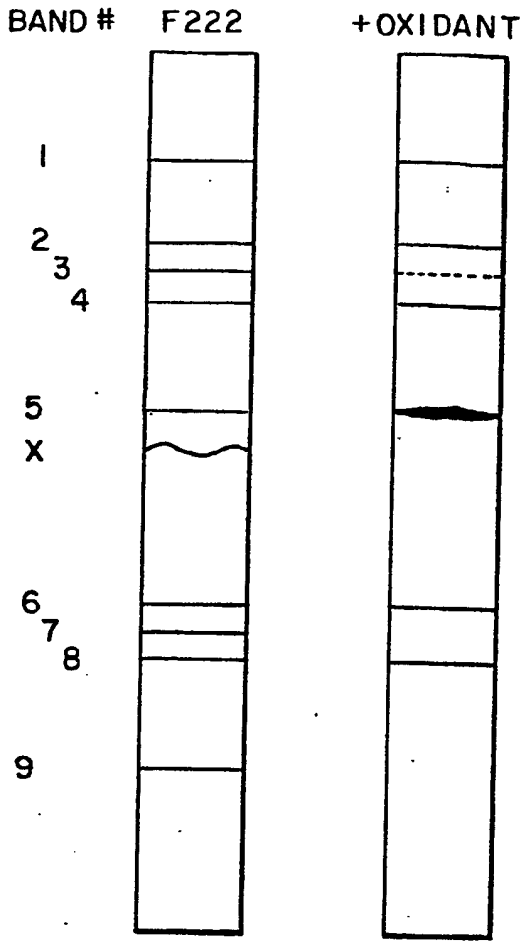

BAND #
F222
+OXIDANT
1
2
3
4
5
X
6
7
8
9

FIG.– 8

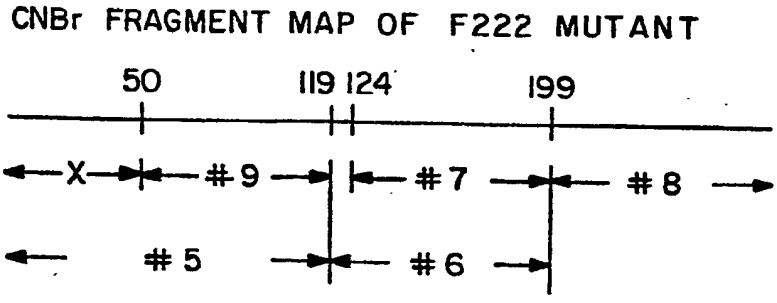

CNBr FRAGMENT MAP OF F222 MUTANT
50
119 124
199
X
#9
#7
#8
#5
#6

FIG.–9

1. Codon number: 43 45

2. Wild type amino acid sequence: Lys-Val-Ala-Gly-Gly-Ala-Ser-Met-Val-Pro-Ser

3. Wild type DNA sequence:

```
5'-AAG-GTA-GCA-GGC-GGA-GCC-AGC-ATG-GTT-CCT-TCT
   TTC-CAT-CGT-CCG-CCT-CGG-TCG-TAC-CAA-GGA-AGA-5'
```

4. pΔ50:

```
        **  *                                *
5'-AAG-GCC-T----------------GC-ATG-GTA-CCT-TCT
   TTC-CGG-A----------------CG-TAC-CAT-GGA-AGA-5'
     Stu I                              Kpn I
```

5. pΔ50 cut with *Stu I/Kpn I*

```
                                          *
5'-AAG-G                                   pCT-TCT
   TTC-Cp                                CAT-GGA-AGA-5'
```

6. Cut pΔ50 ligated with cassettes:

```
                                         *
5'-AAG-GTA-GCA-GGC-GGA-GCC-AGC-ATG-GTA-CCT-TCT
   TCC-CAT-CGT-CCG-CCT-CGG-TCG-TAC-CAT-GGA-AGA-5'
```

7. Mutagenesis primer for pΔ50:

```
                          ***          *
5'-CT-GAT-TTA-AAG-GCC-TGC-ATG-GTA-CCT-TCT-GA
```

8. Mutants made: V45, P45, V45/P48, E46, E48, V48, C49, C50, F50

FIG.—10

1. Codon number:

2. Wild type amino acid sequence:
```
117          120             124     126            130
Asn-Asn-Met-Asp-Val-Ile-Asn-Met-Ser-Leu-Gly-Gly-Pro-Ser
```

3. Wild type DNA sequence:
```
5'-AAC-AAT-ATG-GAC-GTT-ATT-AAC-ATG-AGC-CTC-GGC-GGA-CCT-TCT
   TTG-TTA-TAC-CTG-CAA-TAA-TTG-TAC-TCG-GAG-CCG-CCT-GGA-AGA-5'
```

4. pΔ124:
```
                   * ***                        *   *
5'-AAC-AAT-ATG-GAT-ATC--------------------C-GGG-GGC-CCT-TCT
   TTG-TTA-TAC-CTA-TAG--------------------G-CCC-CCG-GGA-AGA-5'
                Eco RV                           Apa I
```

5. pΔ124 cut with *Eco* RV and *Apa* I
```
                  *                                 *
5'-AAC-AAT-ATG-GAT                                    pCT-TCT
   TTG-TTA-TAC-CTAp                               CCG-GGA-AGA-5'
```

6. Cut pΔ124 ligated with cassettes:
```
                  *                                         *
5'-AAC-AAT-ATG-GAT-GTT-ATT-AAC-ATG-AGC-CTC-GGC-GGC-CCT-TCT
   TTG-TTA-TAC-CTA-CAA-TAA-TTG-TAC-TCG-GAG-CCG-CCG-GGA-AGA-5'
```

7. Mutagenesis primer for pΔ124::
```
                  * ***      *   *
5'-AAC-AAT-ATG-GAT-ATC-C-GGG-GGC-CCT-TCT-GGT-TC-3'
```

8. Mutants made: I 124, L 124 AND C126

FIG.—11

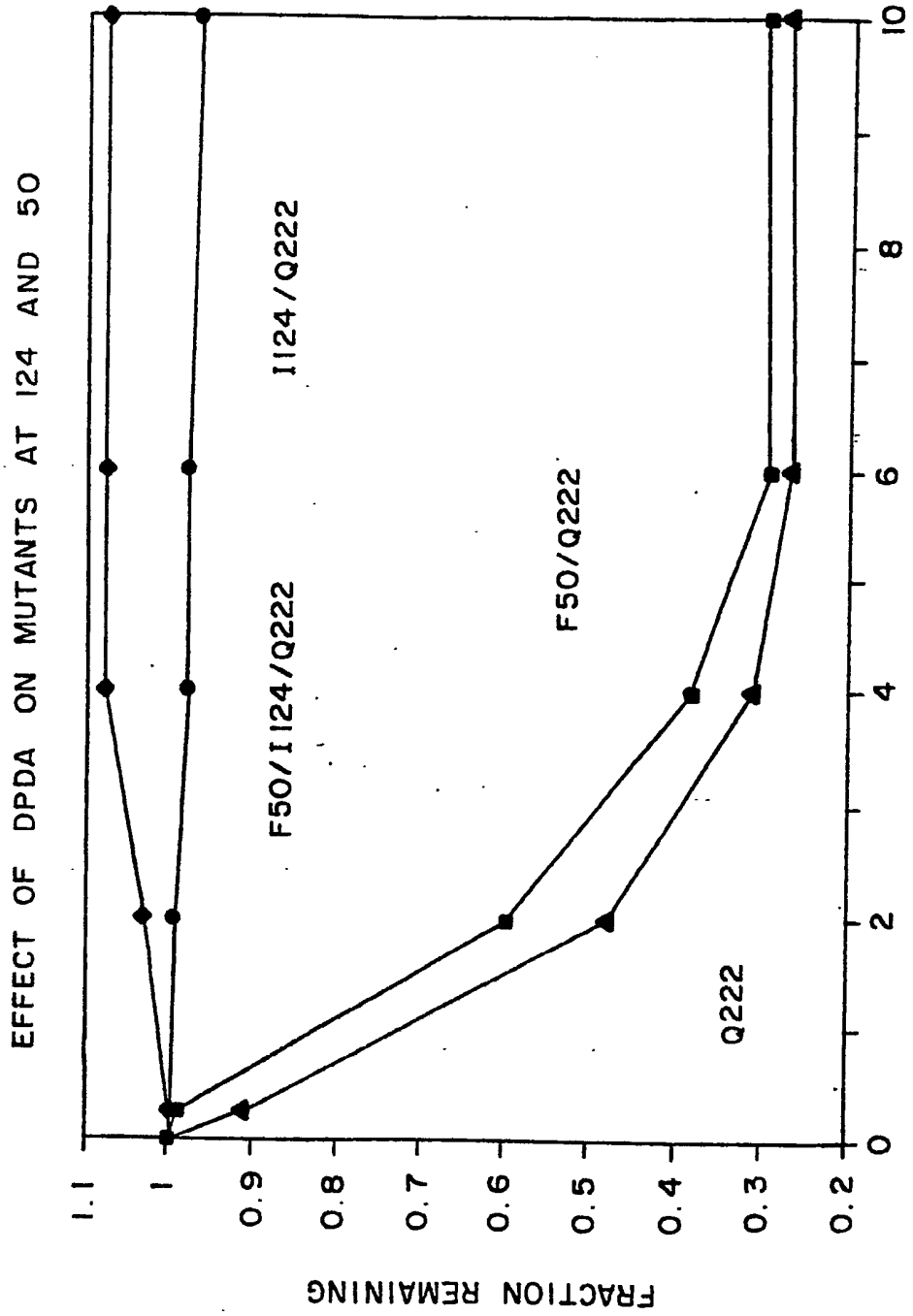

EFFECT OF DPDA ON MUTANTS AT I24 AND 50
I124/Q222
F50/I124/Q222
F50/Q222
Q222
FRACTION REMAINING
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
2
4
6
8
10
MINUTES

FIG.-12

	Codon:	166
	Wild type amino acid sequence:	Thr Ser Gly Ser Ser Ser Thr Val Gly Tyr Pro Gly
1.	Wild type DNA sequence:	5'-ACT TCC GGC AGC TCA AGC ACA GTG GGC TAC CCT GGT-3' 3'-TGA AGG CCG TCG AGT TCG TGT CAC CCG ATG GGA CCA-5'
2.	pΔ166 DNA sequence:	5'-ACT TCC GGG AGC TCA A - - - - - - - - - C CCG GGT-3' 3'-TGA AGG CCC TCG AGT T - - - - - - - - - G GGC CCA-5' SacI XmaI
3.	pΔ166 cut with SacI and XmaI:	5'-ACT TCC GGG AGC T pCCG GGT-3' 3'-TGA AGG CCCp CA-5'
4.	Cut pΔ166 ligated with duplex DNA cassette pools:	5'-ACT TCC GGG AGC TCA AGC ACA GTG NNN TAC CCG GGT-3' 3'-TGA AGG CCC TCG AGT TCG TGT CAC NNN ATG GGC CCA-5'

MUTAGENESIS PRIMER 37 MER

5' AA GGC ACT TCC GGG AGC TCA ACC CGG GTA AA TAC CCT 3'

FIG.—13

0251446

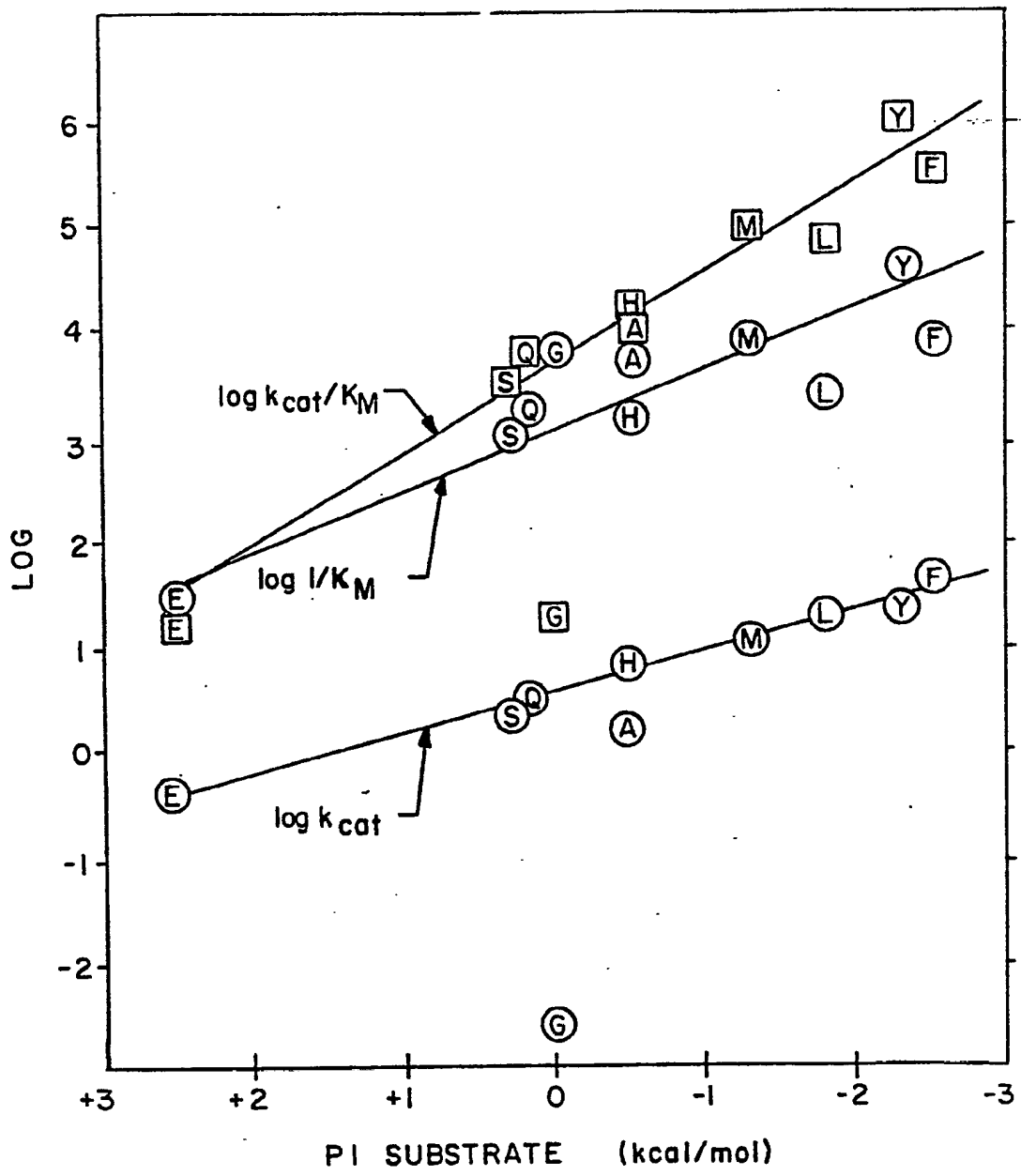

LOG
6
5
4
3
2
1
0
-1
-2
log k_{cat}/K_M
log I/K_M
log k_{cat}
+3
+2
+1
0
-1
-2
-3
PI SUBSTRATE (kcal/mol)

FIG. – 14

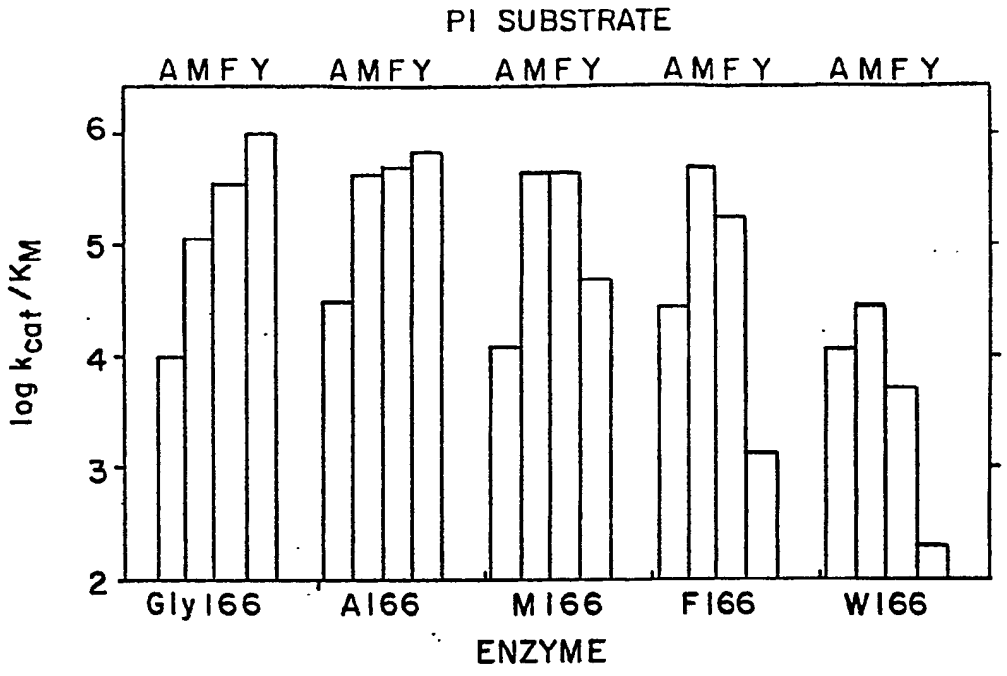


FIG.—15A

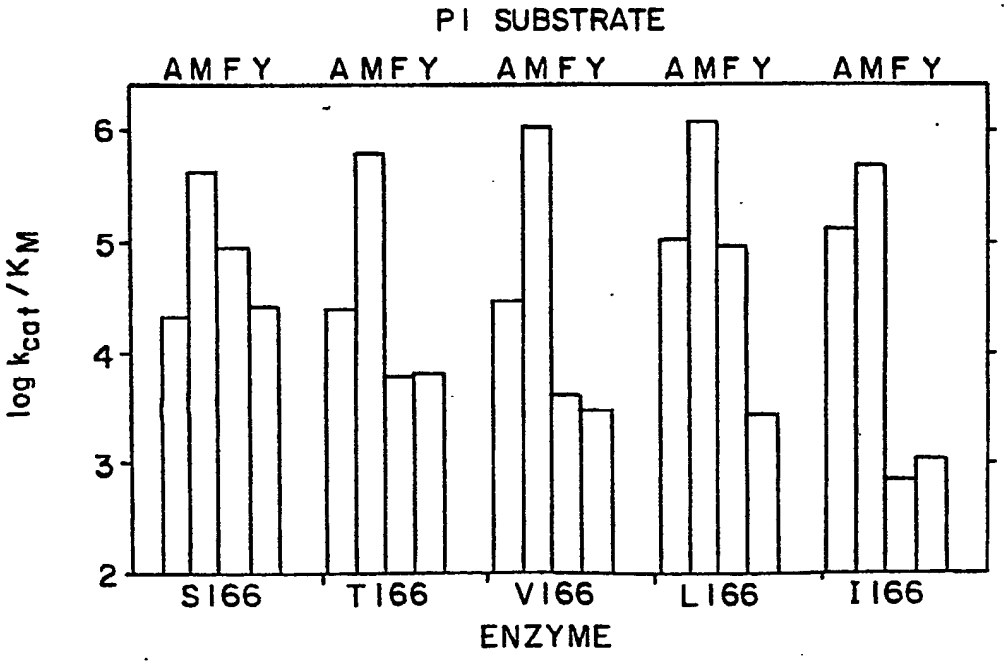


FIG.—15B

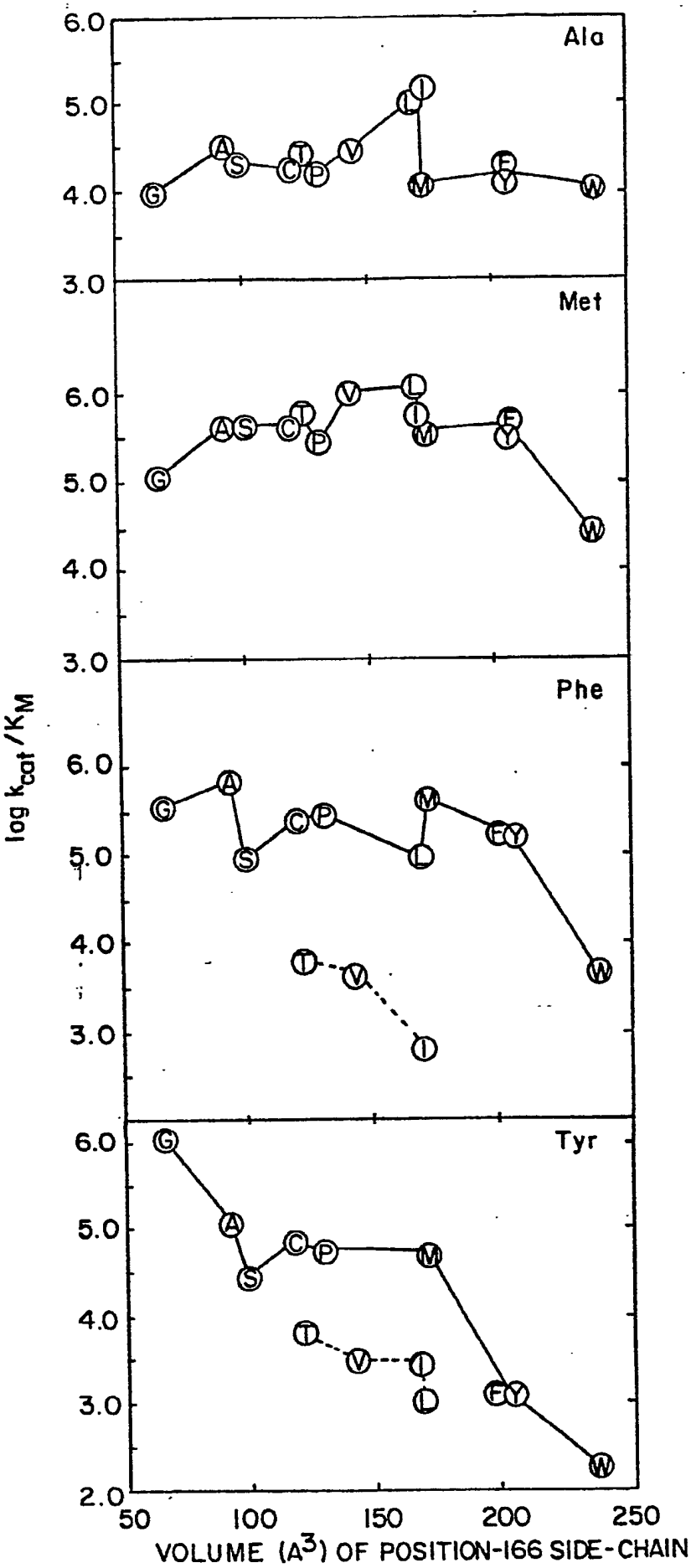

Ala
Met
Phe
Tyr
log k_{cat}/K_M
VOLUME (A^3) OF POSITION-166 SIDE-CHAIN
6.0
5.0
4.0
3.0
2.0
50
100
150
200
250

FIG.-16

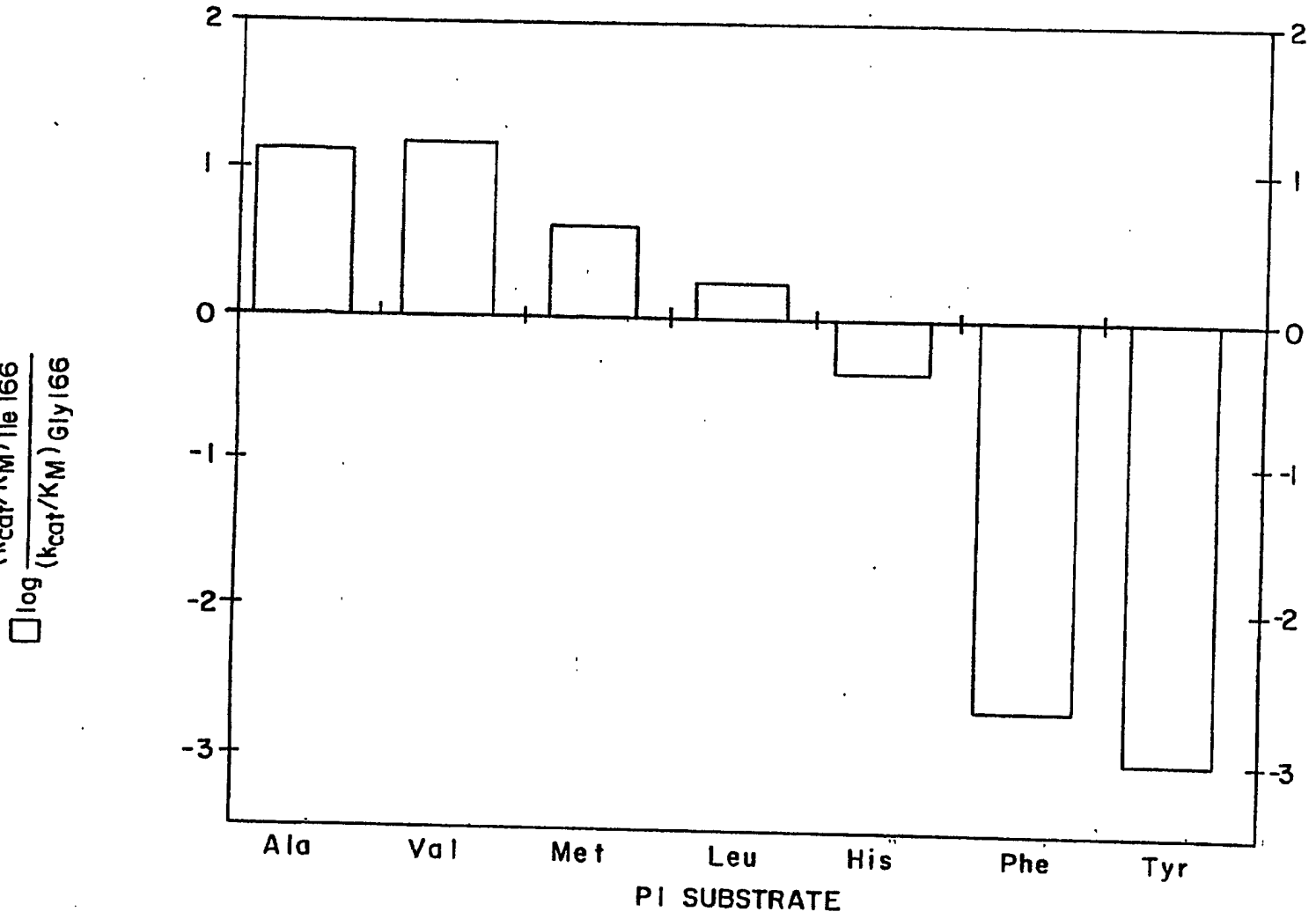

2
1
0
-1
-2
-3
Ala
Val
Met
Leu
His
Phe
Tyr
PI SUBSTRATE
$\square \log \frac{(k_{cat}/K_M)_{Ile\ 166}}{(k_{cat}/K_M)_{Gly\ 166}}$

FIG. – 17

GLY-169 CASSETTE MUTAGENESIS

CODON:		162 169 173
WILD TYPE AMINO ACID SEQUENCE:		SER SER THR VAL GLY TYR PRO GLY LIS TYR PRO SER
1. WILD TYPE DNA SEQUENCE	5'	TCA AGC ACA GTG GGC TAC CCT GGT AAA TAC CCT TCT 3'
	3'	AGT TCG TGT CAC CCG ATG GGA CCA TTT ATG GGA AGA 5'
2. P169 DNA SEQUENCE	5'	TCA AGC ACA GTC GGG TAC CCT-----GA TAT CCT TCT 3'
	3'	AGT TCG TGT CAC CCC ATG GGA CT ATA GGA AGA 5'
		KpnI EcoRV
3. P169 CUT WITH KpnI AND EcoRV:	5'	TAC AGC ACA GTC GGG TAC pAT CCT TCT 3'
	3'	AGT TCG TGT CAC CCp TA GGA AGA 5'
4. CUT P169 LIGATED WITH	5'	TAC AGC ACA GTG GGG TAC CCT NNN AAA TAT CCT TGT 3'
OLIGONUCLEOTIDE POOLS	3'	AGT TCG TGT CAC CCC ATG GGA NNN TTT ATA GGA AGA 5'
MUTAGENESIS PRIMER FOR P169	5'	AAG CAC AGT GGG GTA CCC TGA TAT CCT TCT GTC A 3'

FIG.—18

0251446

1. Codon number: 100 104 105 108

2. Wild type amino acid sequence: Gly-Ser-Gly-Gln-Tyr-Ser-Trp-Ile-Ile-

3. Wild type DNA sequence: 5'-GGT-TCC-GGC-CAA-TAC-AGC-TGG-ATC-ATT-3'
Pvu II

4. Primer for *Hind* III insertion at 104: ****
5'-GGT-TCC-GGC-CAA-GCTT-AGC-TGG-ATC-ATT-3'
Hind III

5. Primers for 104 mutants: ***
5'---T-TCC-GCC-CAA-NNN-AGC-TGG-ATC------3'

6. Mutants made: A, M, L, S, AND HIO4

FIG.—19

0251446

1. Codon number: 148 150 152 155

2. Wild type amino acid sequence: Val-Val-Val-Ala-Ala-Ala-Gly-Asn-Glu

3. Wild type DNA sequence: 5'-GTA-GTC-GTT-GCG-GCA-GCC-GGT-AAC-GAA-3'

4. V152/P153 5'-GTA-GTC-GTT-GCG-GTA-CCC-GGT-AAC-GAA-3'
(* * above GTA-CCC; Kpn I)

5. S 152: 5'-GTA-GTC-GTT-GCG-AGC-GCC-GGT-AAC-GAA-3'
(*** above AGC)

6. G 152: 5'-GTA-GTC-GTT-GCG-GGC-GCC-GGT-AAC-GAA-3'
(** above GGC)

FIG.—20

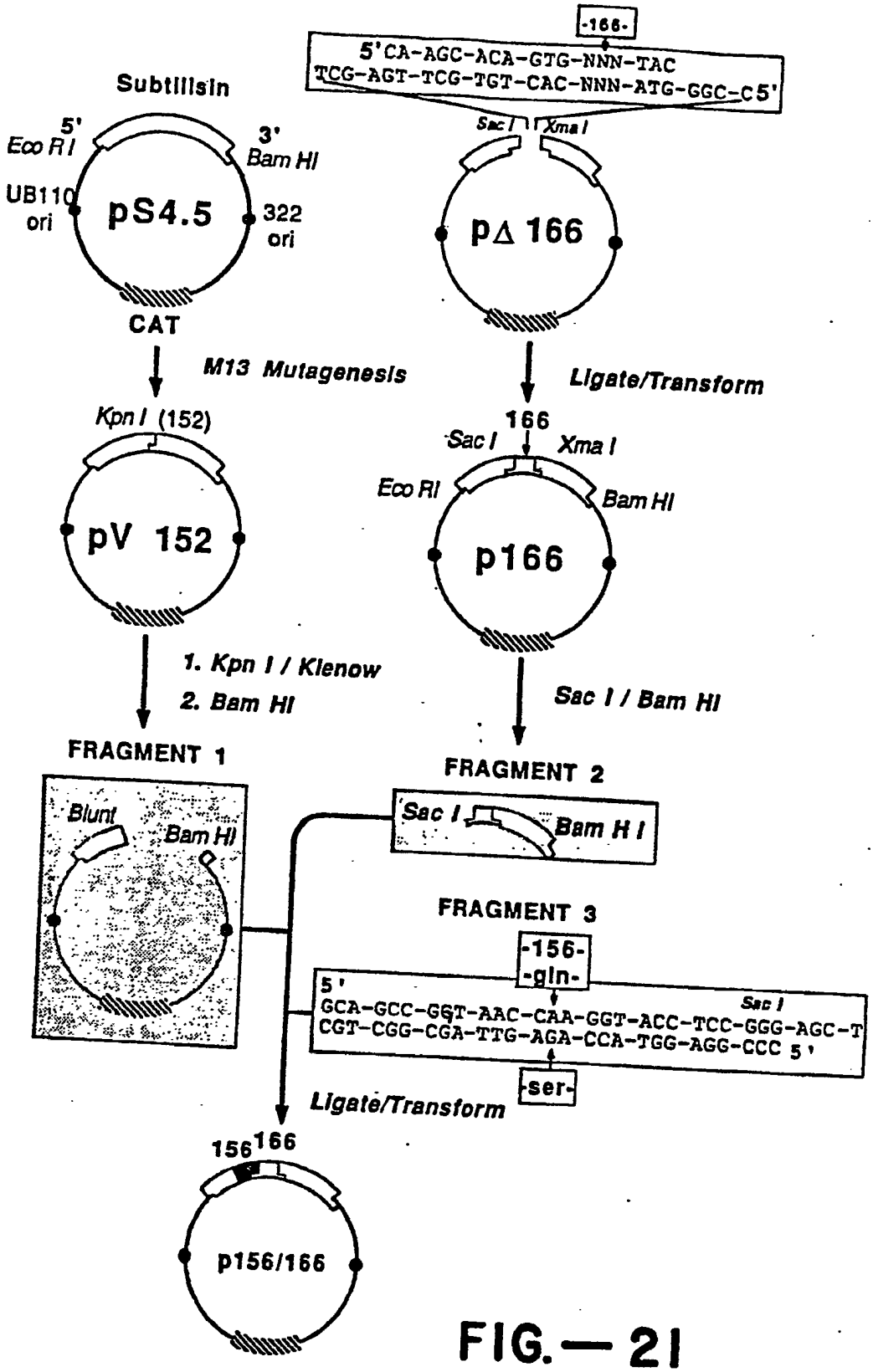

-166-
5'CA-AGC-ACA-GTG-NNN-TAC
TCG-AGT-TCG-TGT-CAC-NNN-ATG-GGC-C5'
Subtilisin
5'
Eco RI
3'
Bam HI
UB110 ori
pS4.5
322 ori
CAT
Sac I
Xma I
pΔ 166
M13 Mutagenesis
Ligate/Transform
Kpn I (152)
pV 152
166
Sac I
Xma I
Eco RI
Bam HI
p166
1. Kpn I / Klenow
2. Bam HI
Sac I / Bam HI
FRAGMENT 1
FRAGMENT 2
Blunt
Bam HI
Sac I
Bam H I
FRAGMENT 3
-156-
-gln-
5'
GCA-GCC-GGT-AAC-CAA-GGT-ACC-TCC-GGG-AGC-T
CGT-CGG-CGA-TTG-AGA-CCA-TGG-AGG-CCC 5'
Sac I
-ser-
Ligate/Transform
156 166
p156/166

FIG.—21

1. Codon number: 211 215 217 220

2. Wild type amino acid sequence: Gly-Asn-Lys-Tyr-Gly-Ala-Tyr-Asn-Gly-Thr-Ser-Met-Ala

3. Wild type DNA sequence:
5'-GGA-AAC-AAA-TAC-GGG-GCG-TAC-AAC-GGT-ACG-TCA-ATG-GCA
CCT-TTG-TTT-ATG-CCC-CGC-ATG-TTG-CCA-TGC-AGT-TAC-CGT-5'

4. pΔ217
5'-GGA-AAC-AAA-TAC-GGC-GCC-TAC------GG-ATA-TCA-ATG-GCA
CCT-TTG-TTT-ATG-CCG-CGG-ATG------CC-TAT-AGT-TAC-CGT-5'
Nar I *Eco* RV

5. pΔ217 cut with *Nar* I and *Eco* RI
5'-GGA-AAC-AAA-TAC-GG
CCT-TTG-TTT-ATG-CCG-Gp
pA-TCA-ATG-GCA
T-AGT-TAC-CGT-5'

6. Cut pΔ217 ligated with cassettes:
5'-GGA-AAC-AAA-TAC-GGC-GCG-NNN-AAC-GGT-ACA-TCA-ATG-GCA
CCT-TTG-TTT-ATG-CCG-CGC-NNN-TTG-CCA-TGT-AGT-TAC-CGT-5'

7. Mutagenesis primer for pΔ217:
5'-GA-AAC-AAA-TAC-GGC-GCC-TAC-GGA-TAT-CAA-TGG-CAT-3'

8. Mutants made: All 19 at 217

FIG.—22

0251446

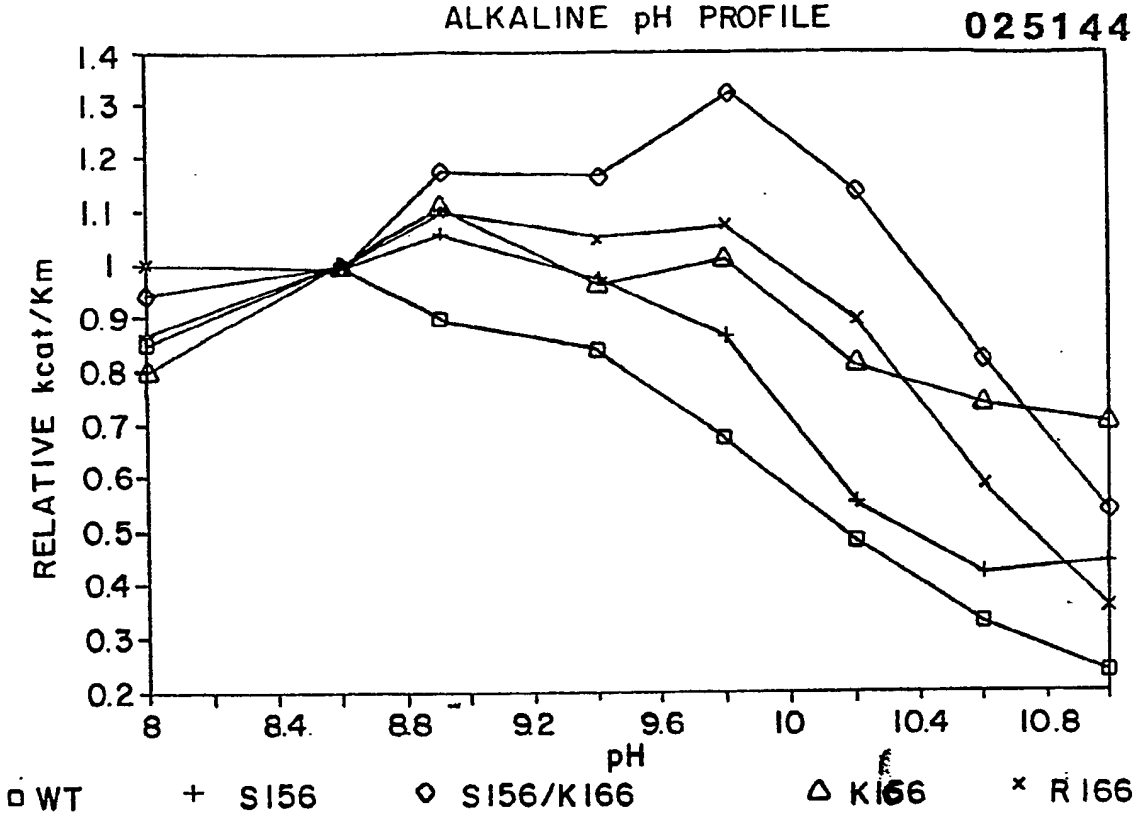


FIG. — 23A

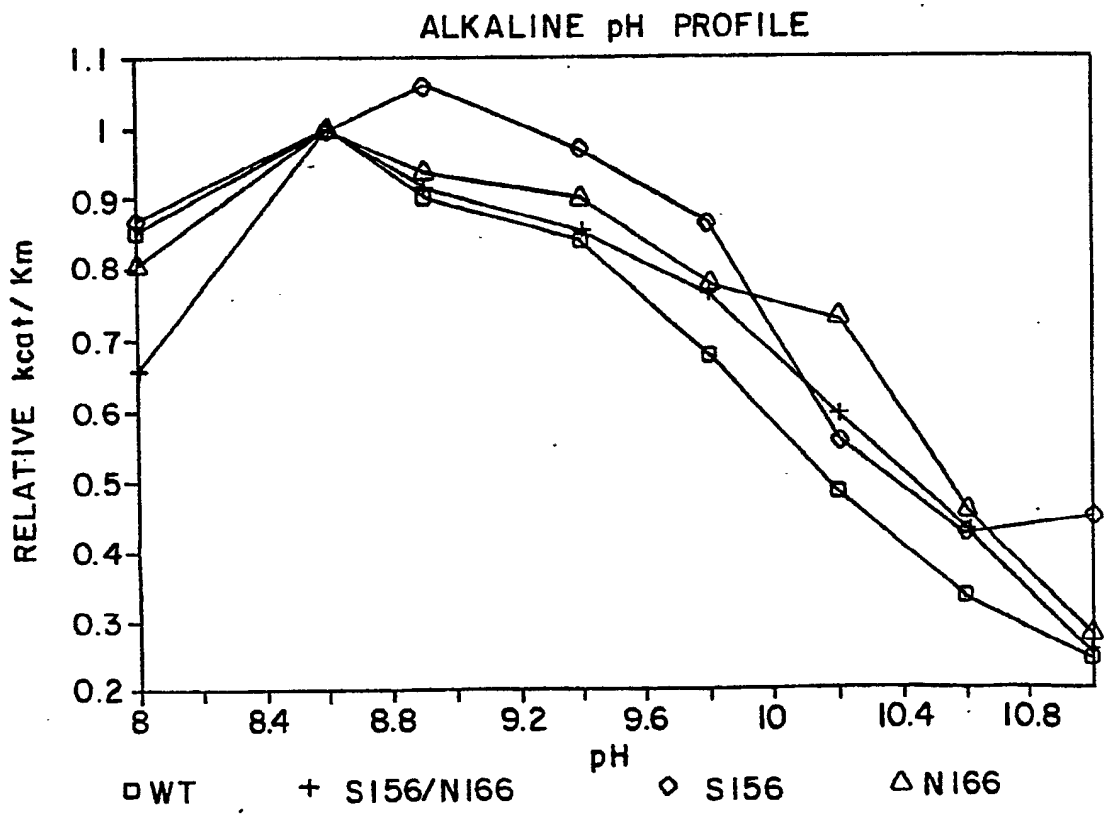


FIG. — 23B

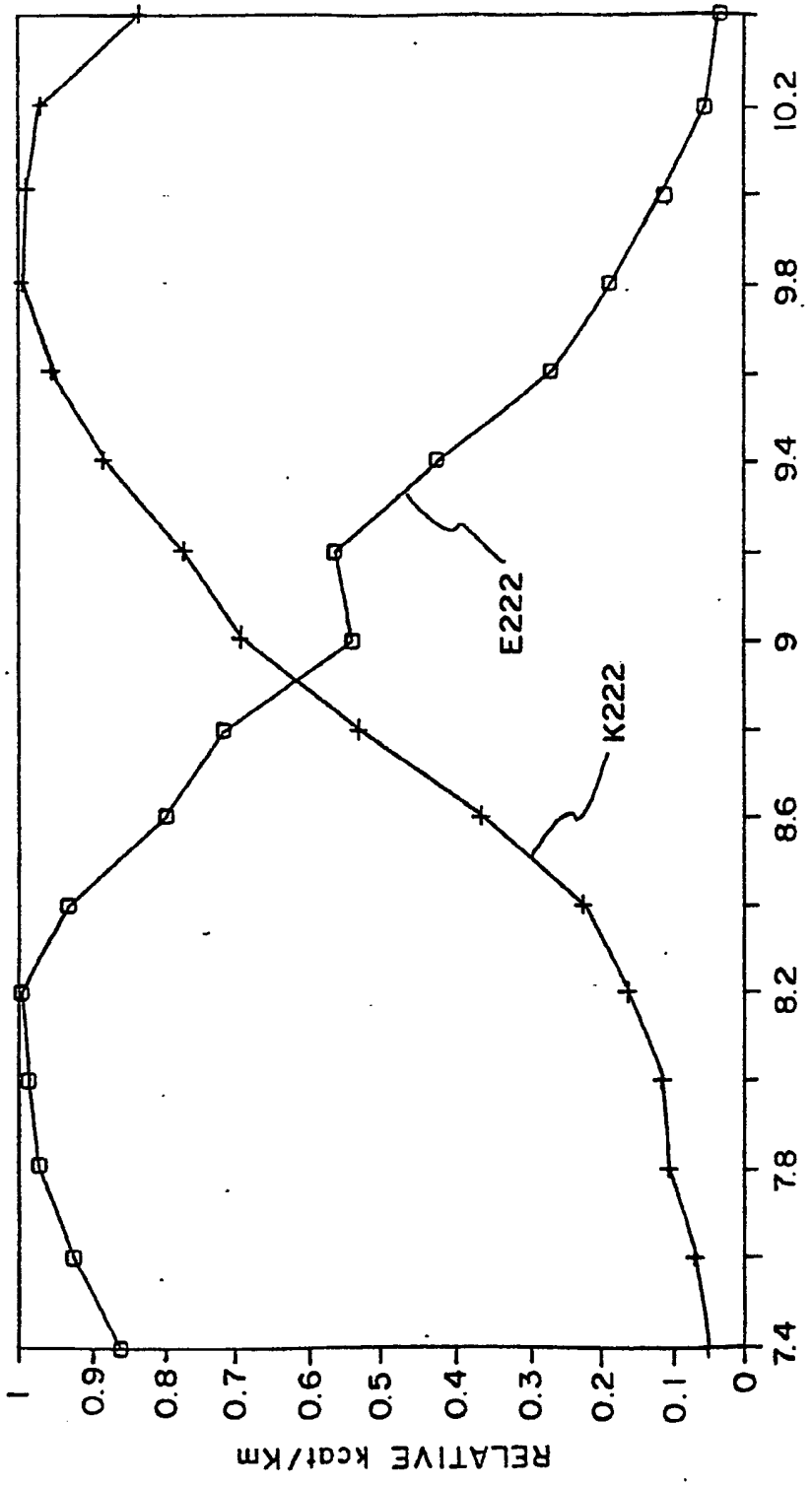

RELATIVE kcat/Km
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.4
7.8
8.2
8.6
9
9.4
9.8
10.2
pH
E222
K222

FIG.—24

1. Codon number: 91 95 100

2. Wild type amino acid sequence: Tyr-Ala-Val-Lys-Val-Leu-Gly-Ala-Asp-Gly-Ser

3. Wild type DNA sequence:
```
5'-TAC-GCT-GTA-AAA-GTT-CTC-GGT-GCT-GAC-GGT-TCC
   ATG-CGA-CAT-TTT-CAA-GAG-CCA-CGA-CTG-CCA-AGG-5'
```

4. pΔ95:
```
      * *                    * *
5'-TAC-GCG-T----------CTC-GCT-GCA-GAC-GGT-TCC
   ATG-CGC-A----------GAG-CGA-CGT-CTG-CCA-AGG-5'
    Mu I                   Pst I
```

5. pΔ95 cut with *Mu* I and *Pst* I
```
5'-TA    *                    * pGAC-GGT-TCC
   ATG-CGCp                  A-CGT-CTG-CCA-AGG-5'
```

6. Cut pΔ95 ligated with cassettes:
```
       *                      *
5'-TAC-GCG-GTA-AAA-GTT-CTC-GGT-GCA-GAC-GGT-TCC
   ATG-CGC-CAT-TTT-CAA-GAG-CCA-CGT-CTG-CCA-AGG-5'
```

7. Mutagenesis primer for pΔ95:
```
                        * *     *   *
5'-CA-TCA-CTT-TAC-GCG-T-CTC-GCT-GCA-GAC-GGT-TCC
```

8. Mutants made: C94, C95, D96

FIG.—25

0251446

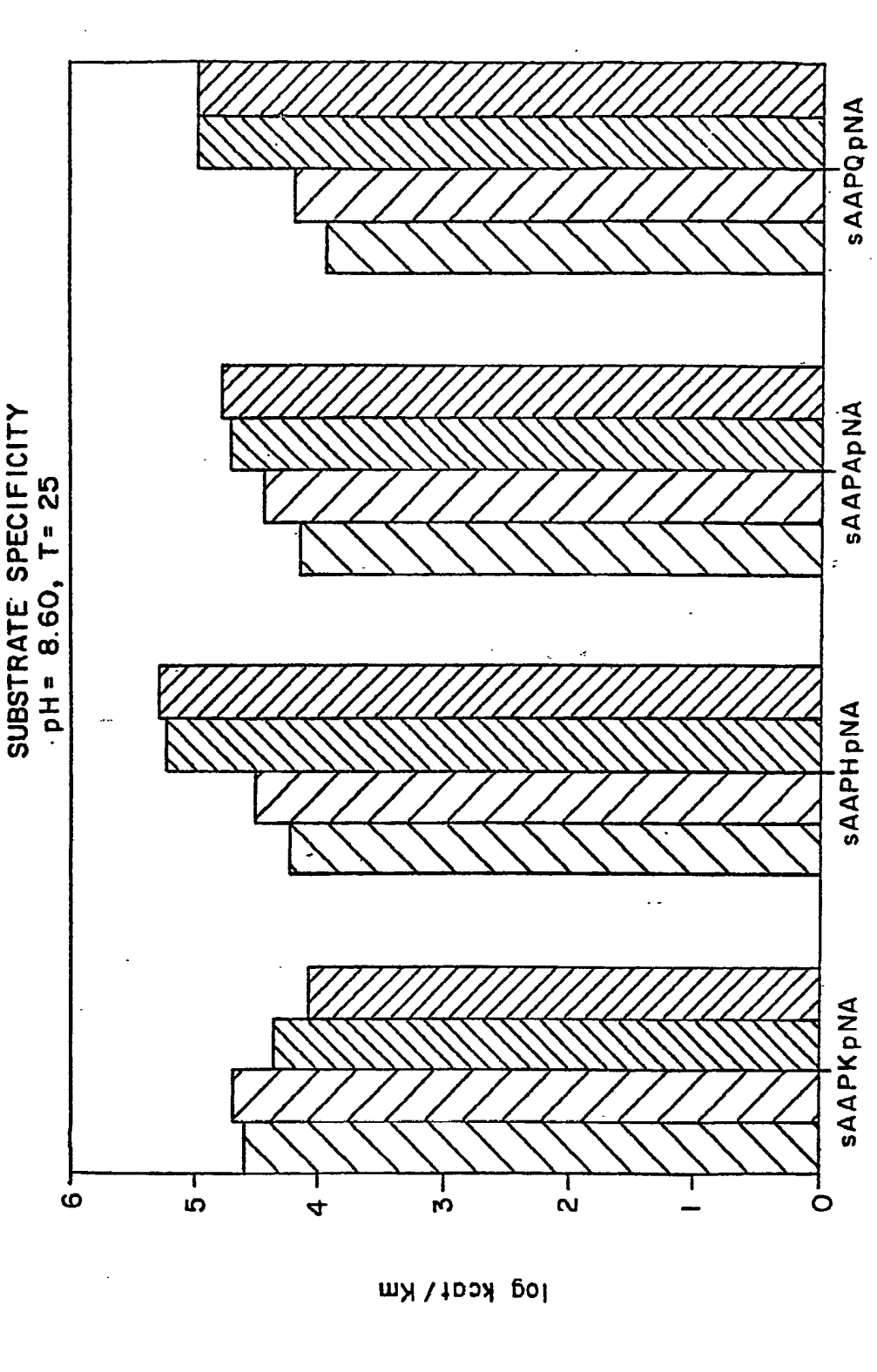

SUBSTRATE SPECIFICITY
pH= 8.60, T= 25
log kcat / Km
0
1
2
3
4
5
6
sAAPKpNA
sAAPHpNA
sAAPApNA
sAAPQpNA
SUBSTRATE
B.A. SUBT
L 217
B.L. SUBT.
FSAL

FIG.—26

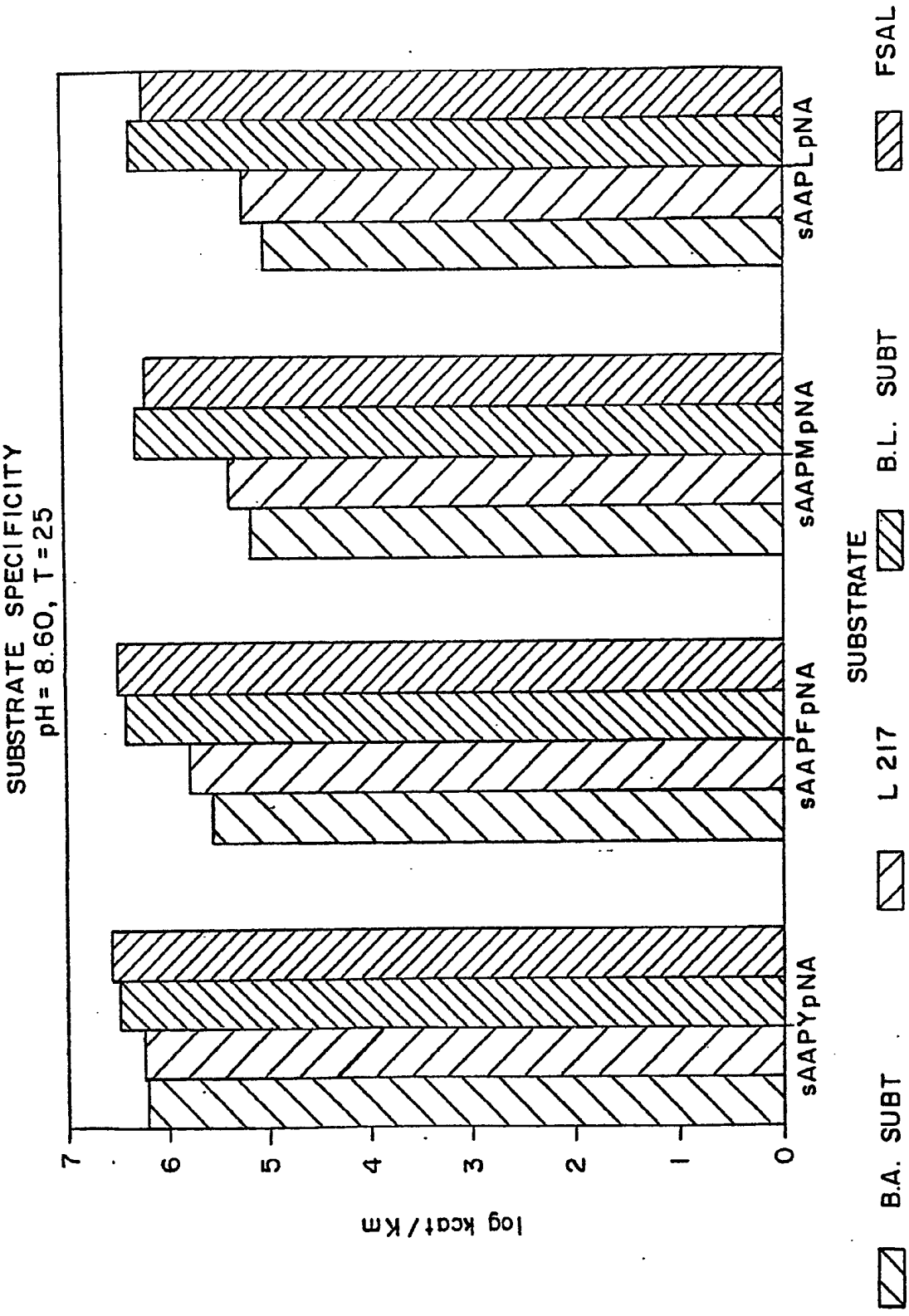

SUBSTRATE SPECIFICITY
pH = 8.60, T = 25
log kcat / km
0
1
2
3
4
5
6
7
sAAPYpNA
sAAPFpNA
sAAPMpNA
sAAPLpNA
SUBSTRATE
B.A. SUBT
L 217
B.L. SUBT
FSAL

FIG. — 27

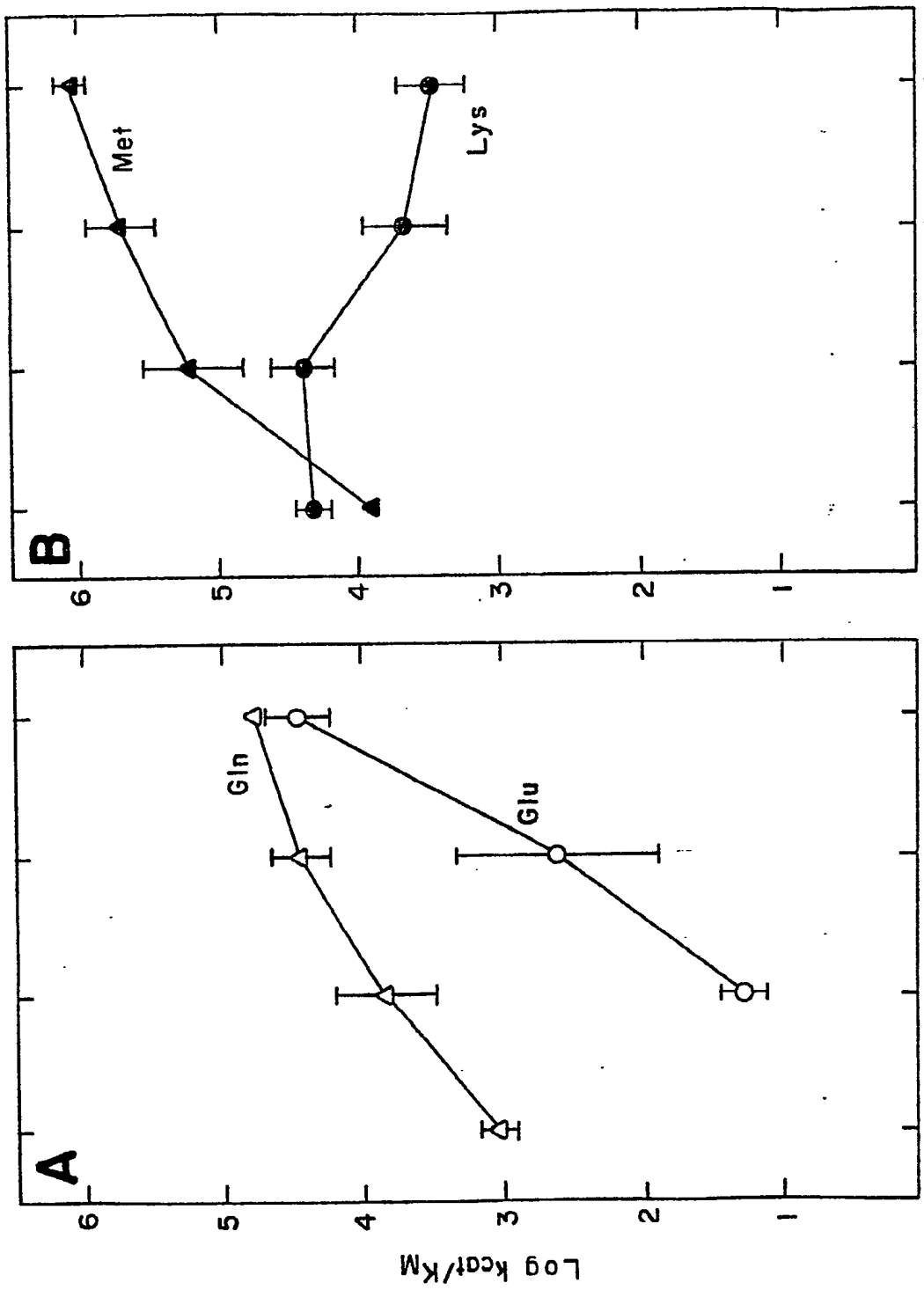

A
B
Gln
Glu
Met
Lys
Log kcat/KM
CHARGE OF PI BINDING SITE
+1
0
-1
-2
1
2
3
4
5
6

FIG.—28

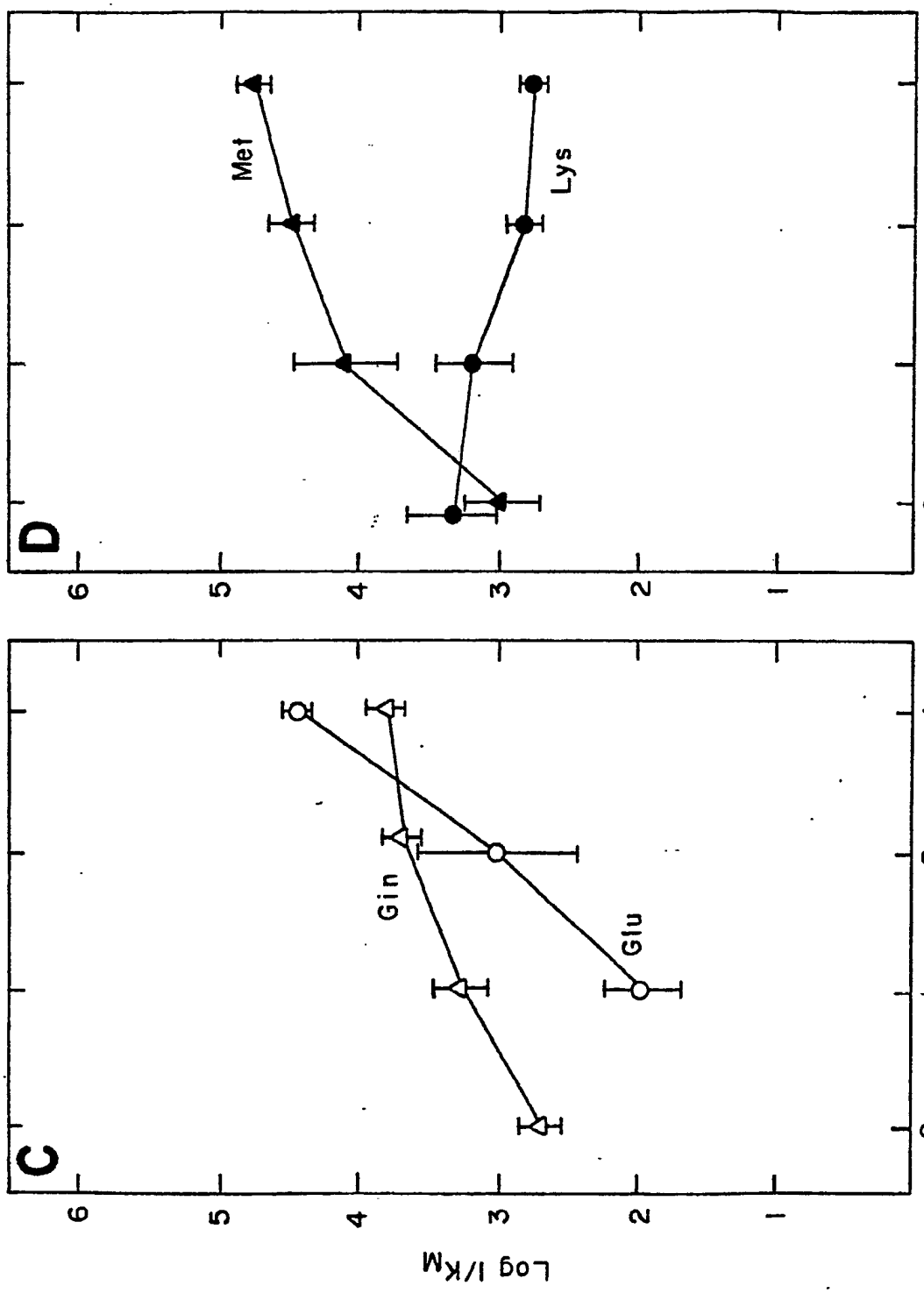

C
D
Met
Lys
Gln
Glu
Log 1/KM
CHARGE OF PI BINDING SITE
-2
-1
0
+1
1
2
3
4
5
6

FIG. -28

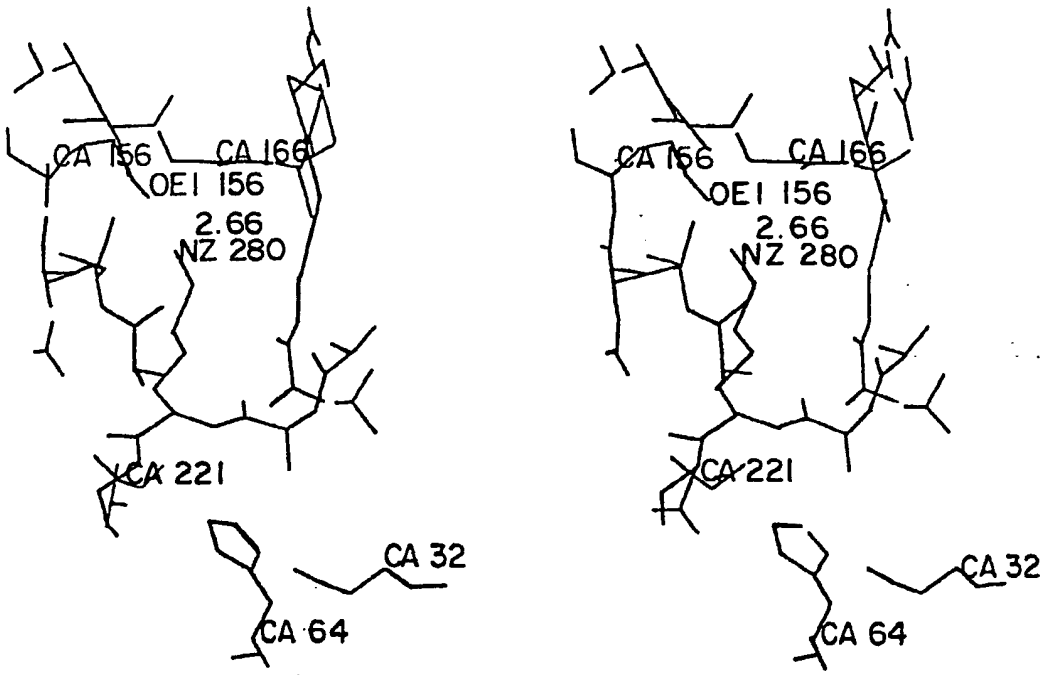


FIG.—29A

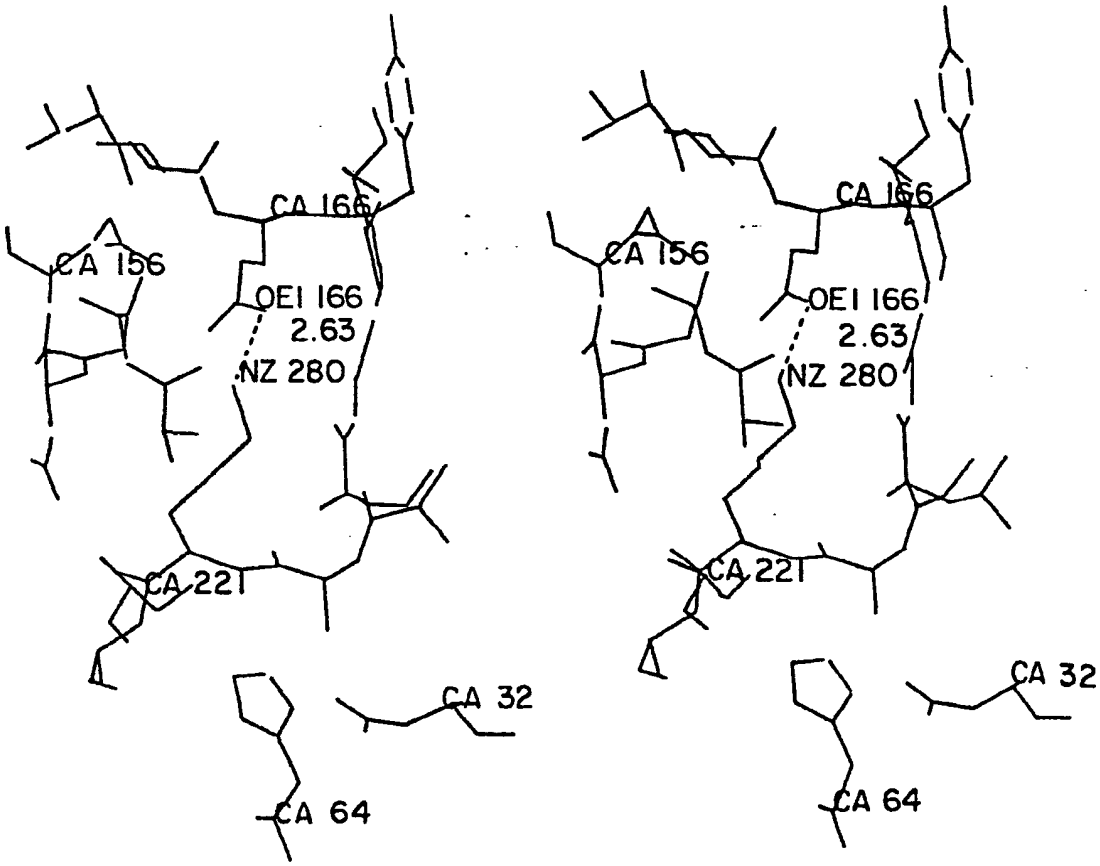


FIG.—29B

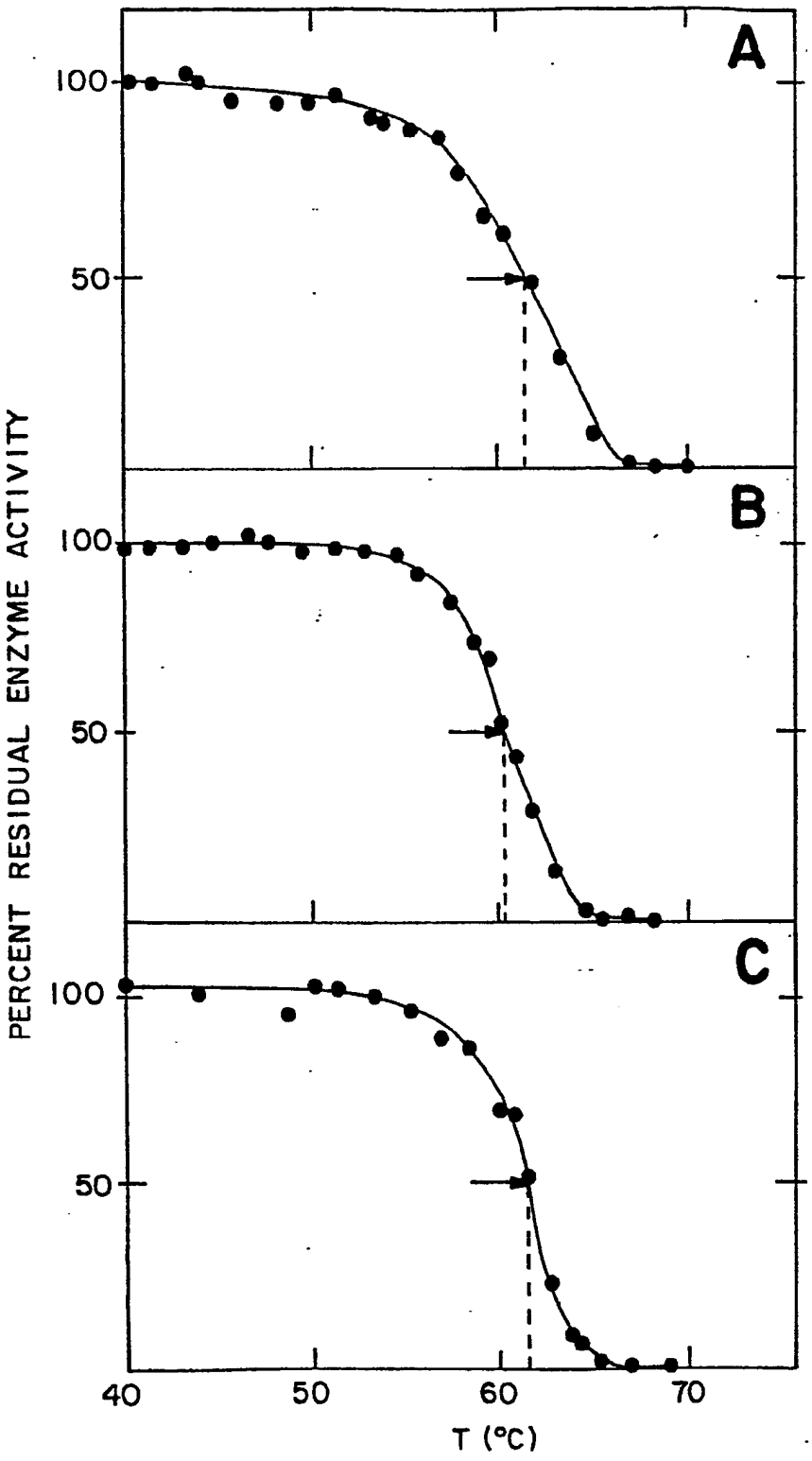

A
B
C
100
50
100
50
100
50
PERCENT RESIDUAL ENZYME ACTIVITY
40
50
60
70
T (°C)

FIG.—30

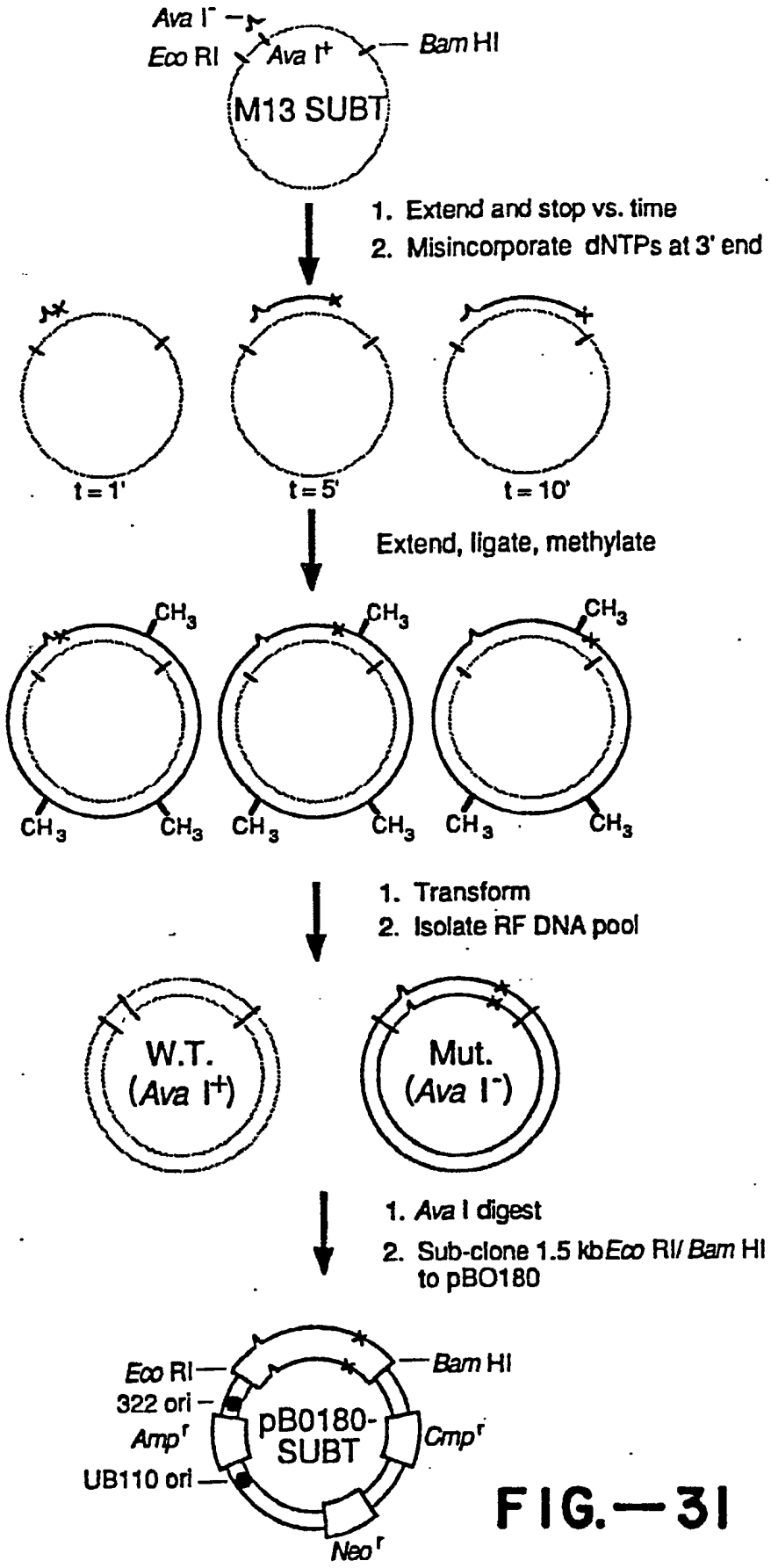

Ava I⁻
Eco RI
Ava I⁺
Bam HI
M13 SUBT
1. Extend and stop vs. time
2. Misincorporate dNTPs at 3' end
t = 1'
t = 5'
t = 10'
Extend, ligate, methylate
CH3
1. Transform
2. Isolate RF DNA pool
W.T.
(Ava I⁺)
Mut.
(Ava I⁻)
1. Ava I digest
2. Sub-clone 1.5 kb Eco RI/ Bam HI
to pBO180
Eco RI
Bam HI
322 ori
Amp^r
pB0180-
SUBT
Cmp^r
UB110 ori
Neo^r

FIG.—31

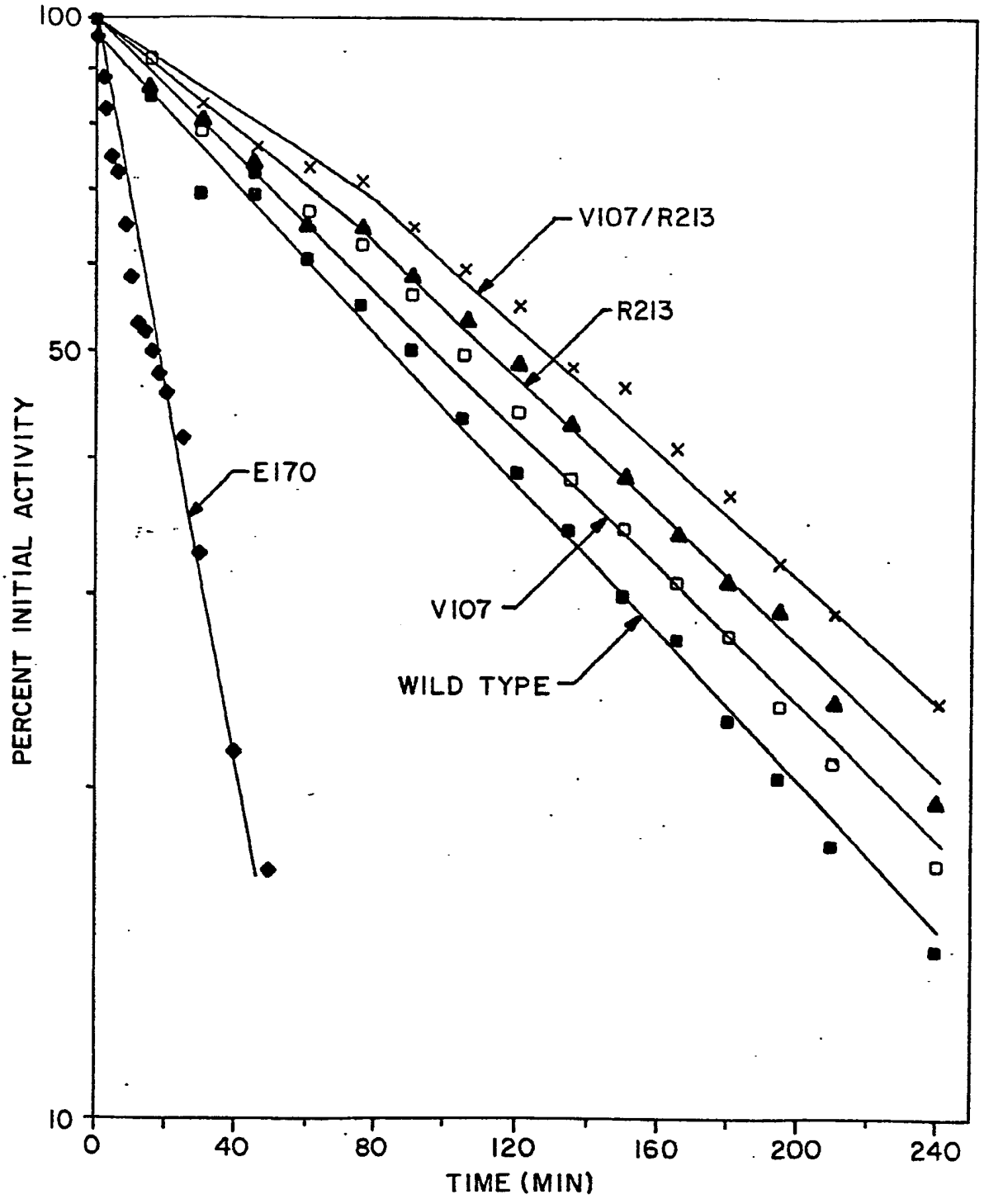

100
50
10
PERCENT INITIAL ACTIVITY
0
40
80
120
160
200
240
TIME (MIN)
V107/R213
R213
E170
V107
WILD TYPE

FIG.-32

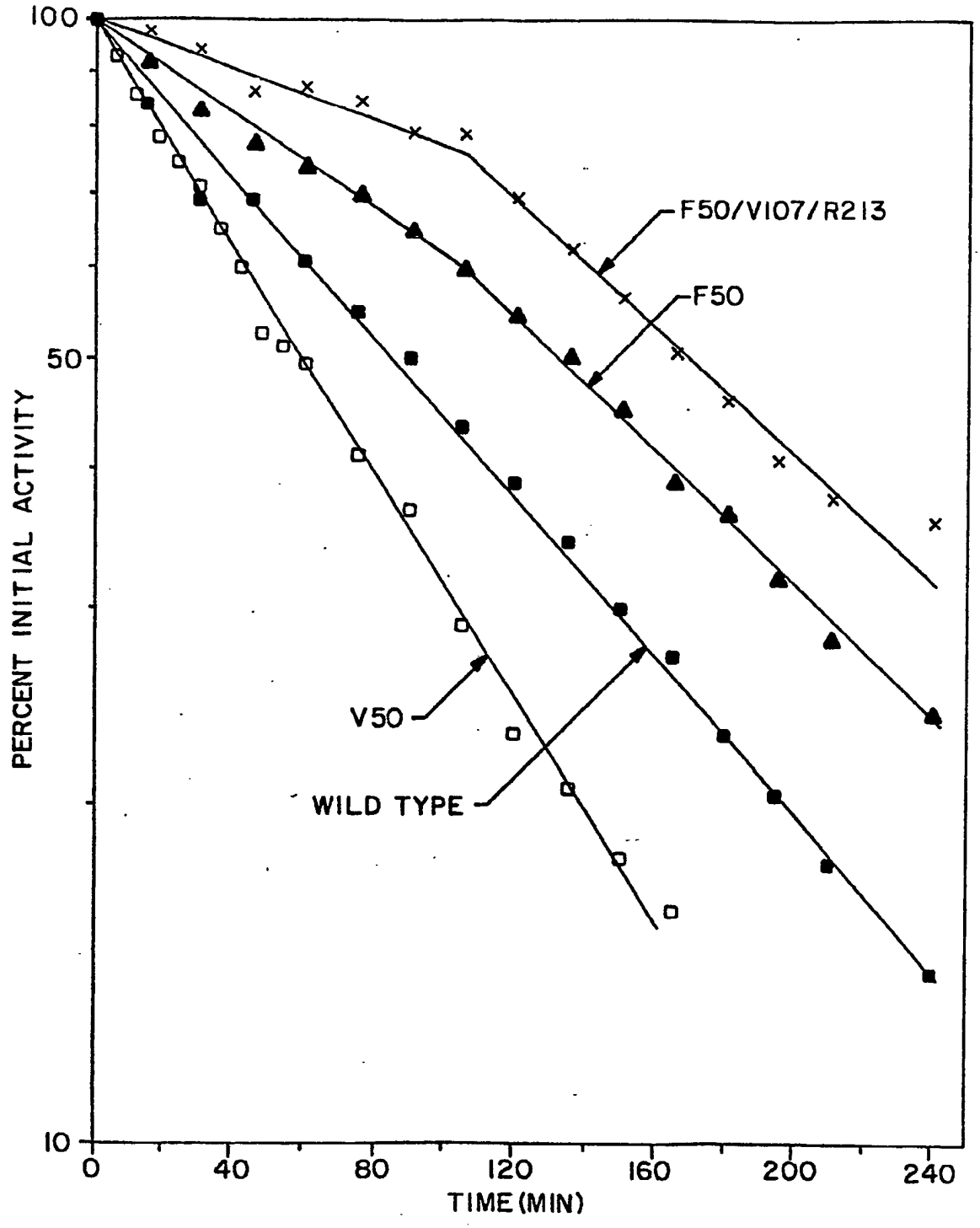

100
50
10
PERCENT INITIAL ACTIVITY
0
40
80
120
160
200
240
TIME (MIN)
F50/V107/R213
F50
V50
WILD TYPE

FIG.-33

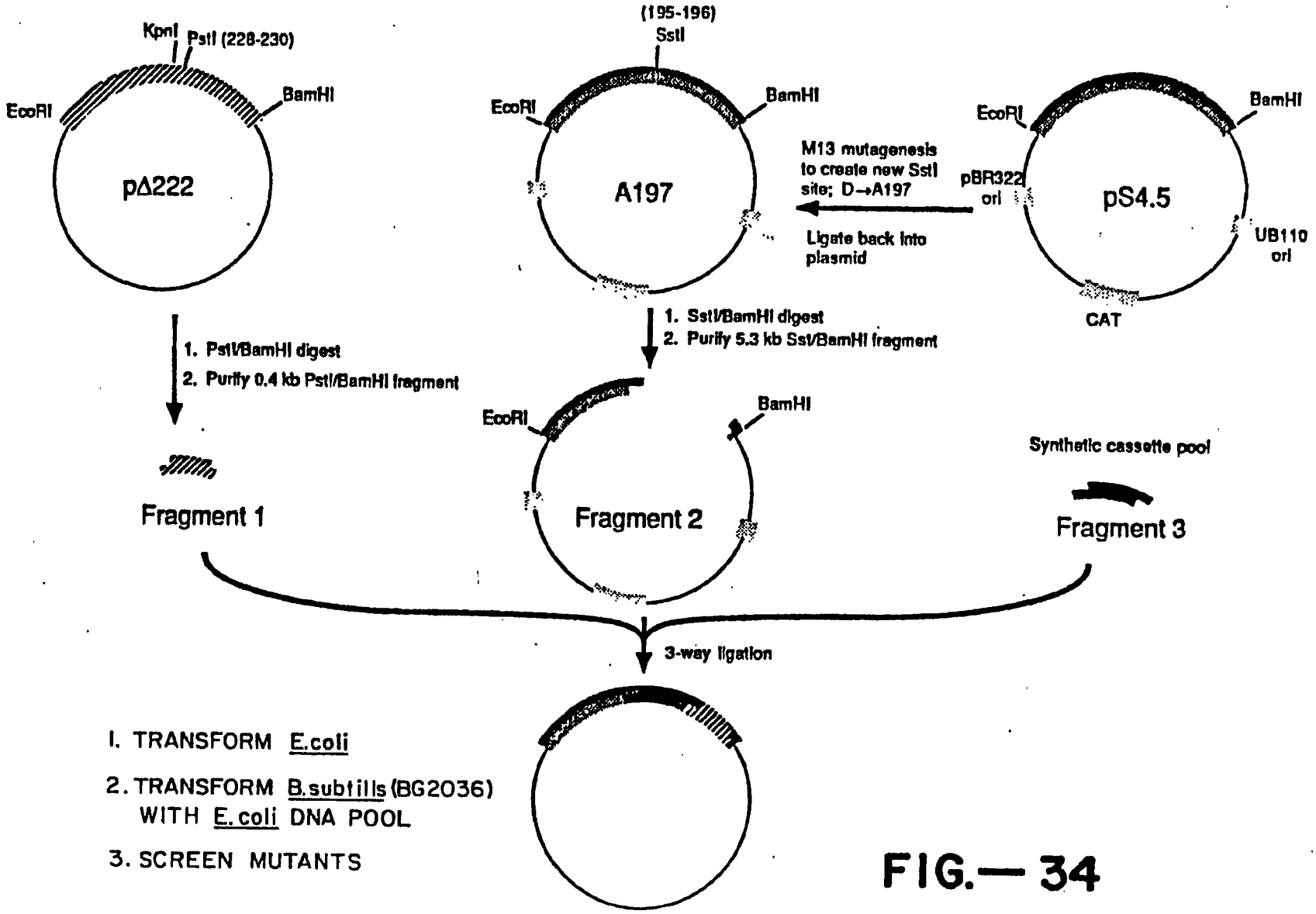


FIG.— 34

0251446

```
                    195                 200                 206
W.T A.A.:    Glu Leu Asp Val Met Ala Pro Gly Val Ser Ile Gln

W.T. DNA:    GAG CTT GAT GTC ATG GCA CCT GGC GTA TCT ATC CAA
             CTC GAA CTA CAG TAC CGT GGA CCG CAT AGA TAG GTT

pΔ222DNA:    GAG CTT GAT GTC ATG GCA CCT GGC GTA TCT ATC CAA
             CTC GAA CTA CAG TAC CGT GGA CCG CAT AGA TAG GTT

A197 DNA:    GAG CTC GCA GTC ATG GCA CCT GGC GTA TCT ATC CAA
             CTC GAG CGT CAG TAC CGT GGA CCG CAT AGA TAG GTT
              SstI

Fragments from
pΔ222 and A197
cut w/ PstI, SstI:
             GAG-CT
             Cp

pΔ222, A197
cut & ligated
w/ oligodeoxy-
nucleotide pools:
             GAG CTC GAT GTC ATG GCA CCT GGC GTA TCT ATC CAA
             CTC GAG CTA CAG TAC CGT GGA CCG CAT AGA TAG GTT
              SstI

                    207         210                 218
W.T A.A.:    Ser Thr Leu Pro Gly Asn Lys Tyr Gly Ala Tyr Asn

W.T. DNA:    AGC ACG CTT CCT GGA AAC AAA TAC GGG GCG TAC AAC
             TCG TGC GAA GGA CCT TTG TTT ATG CCC CGC ATG TTG

pΔ222DNA:    AGC ACG CTT CCT GGA AAC AAA TAC GGG GCG TAC AAC
             TCG TGC GAA GGA CCT TTG TTT ATG CCC CGC ATG TTG

A197 DNA:    AGC ACG CTT CCT GGA AAC AAA TAC GGG GCG TAC AAC
             TCG TGC GAA GGA CCT TTG TTT ATG CCC CGC ATG TTG

Fragments from
pΔ222 and A197
cut w/ PstI, SstI:
             AGC ACG CTT CCC GGG AAC AAA TAC GGG GCG TAC AAC
             TCG TGC GAA GGG CCC TTG TTT ATG CCC CGC ATG TTG
                         SmaI

                    219 220                         230
W.T A.A.:    Gly Thr Ser Met Ala Ser Pro His Val Ala Gly Ala

W.T. DNA:    GGT ACG TCA ATG GCA TCT CCG CAC GTT GCC GGA GCG-3'
             CCA TGC AGT TAC CGT AGA GGC GTG CAA CGG CCT CGC-5'

pΔ222DNA:    GGT ACC TCA----------CG CAC GCT GCA GGA GCG-3'
             CCA TGG AGT----------GC GTG CGA CGT CCT CGC-5'
              KpnI                          PstI

A197 DNA:
             GGT ACG TCA ATG GCA TCT CCG CAC GTT GCC GGA GCG-3'
             CCA TGG AGT TAC CGT AGA GGC GTG CAA GTG CCT CGC-5'

Fragments from
pΔ222 and A197
cut w/ PstI, SstI:
                                                pGGA GCG-3'
                                             A CGT CCT CGC-5'

pΔ222, A197
cut & ligated
w/ oligodeoxy-
nucleotide pools:
             GGT ACC TCA ATG GCA TCT CCG CAC GTT GCA GGA GCG-3'
             CCA TGG AGT TAC CGT AGA GGC GTG CAA CGT CCT CGC-5'
              KpnI                          PstI destroyed
```

Oligodeoxynucleotide pools synthesized with 2% contaminating nucleotides in each cycle to give ~15% of pool with 0 mutations, ~28% of pool with single mutations, and ~57% of pool with 2 or more mutations, according to the general formula $f = \frac{\mu^n}{n!} e^{-\mu}$.

FIG.—35

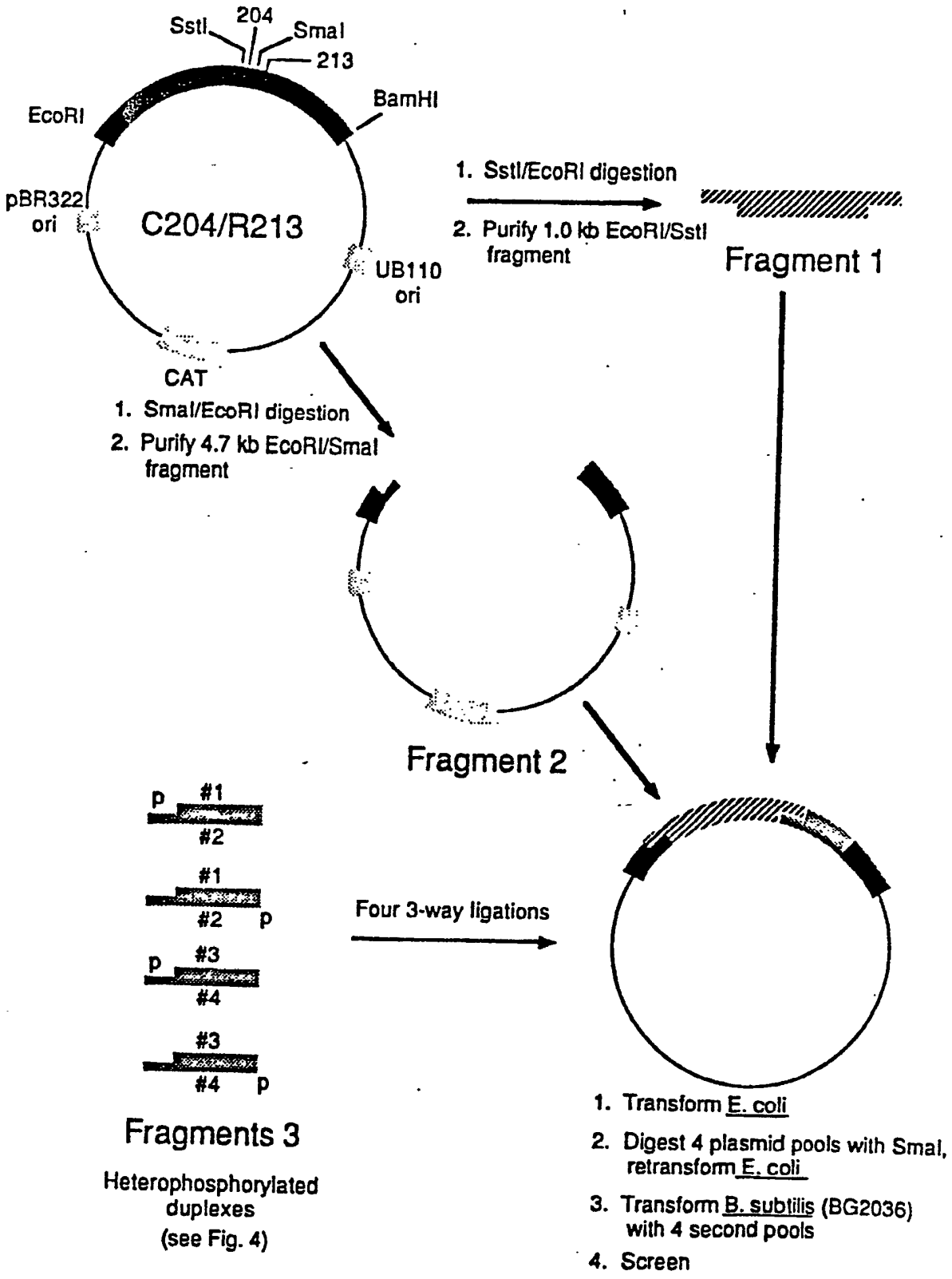

SstI
204
SmaI
213
BamHI
EcoRI
pBR322 ori
C204/R213
UB110 ori
CAT
1. SstI/EcoRI digestion
2. Purify 1.0 kb EcoRI/SstI fragment
Fragment 1
1. SmaI/EcoRI digestion
2. Purify 4.7 kb EcoRI/SmaI fragment
Fragment 2
p #1
#2
#1
#2 p
p #3
#4
#3
#4 p
Four 3-way ligations
Fragments 3
Heterophosphorylated duplexes
(see Fig. 4)
1. Transform E. coli
2. Digest 4 plasmid pools with SmaI, retransform E. coli
3. Transform B. subtilis (BG2036) with 4 second pools
4. Screen

FIG.—36

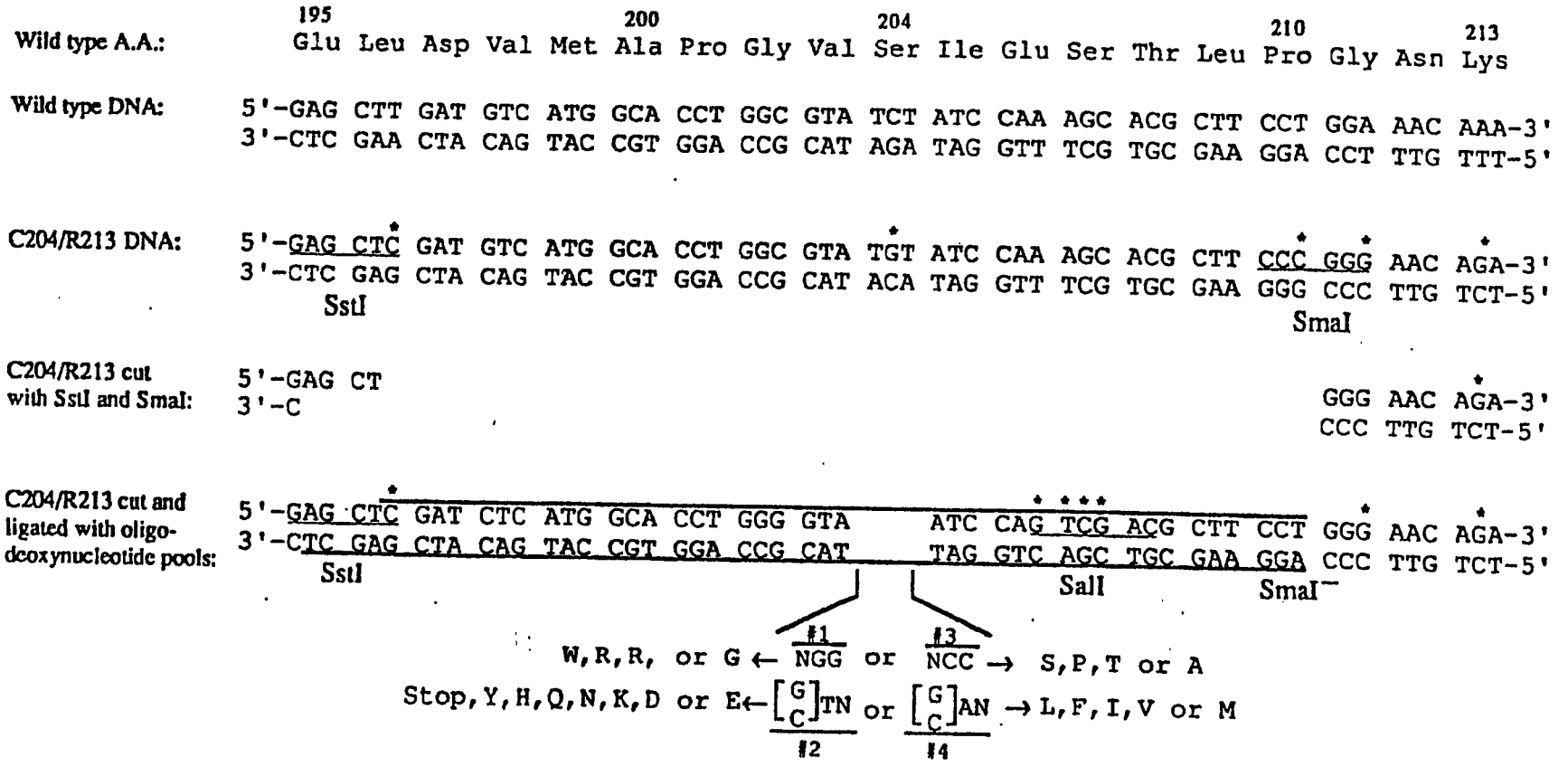


FIG.—37

0251446